131

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REPORT OF INVESTIGATIONS—NO. 131

MARINE POOL, MADISON COUNTY, ILLINOIS SILURIAN-REEF PRODUCER

BY

HEINZ A. LOWENSTAM

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MARINE POOL, MADISON COUNTY, ILLINOIS, SILURIAN REEF PRODUCER[1]

HEINZ A. LOWENSTAM[2]
Urbana, Illinois

ABSTRACT

The Marine pool, Madison County, Illinois, was discovered in 1943. It yielded the first known production of oil from a Silurian reef in Illinois. The principal producing zone is a coquina-like detrital limestone which forms the mantling deposit of a Niagaran reef.

The reef is horseshoe-shaped with a subsidiary fore-reef belt east of the main reef. There is 120 feet of closure over the reef area. The reef topography, although reflected in the structure of the post-Silurian strata, is less pronounced in successively higher beds. The Ordovician conforms to the regional dip in the two deep tests that were drilled through the flanks of the reef. The Marine pool structure is, therefore, interpreted as due to the local increase in thickness and to the rigid unyielding frame of the Niagaran reef deposits in the surrounding compactable silty and argillaceous normal extra-reef strata.

As many as four porous discontinuous streaks have been reported in the principal producing zone of the Silurian limestone that caps the reef. The oil production appears to be out of proportion with respect to the storage capacity of the discontinuous streaks. Secondary porosity zones in the wall-rock adjacent to sand-filled and clay-filled fissures indicate a porous network that connects the discontinuous streaks and extends into the underlying reef core.

The solution-enlarged fissures extend in great numbers from the post-Wapsipinicon unconformity of Middle Devonian age, downward into the Silurian deposits. Devonian production of a few wells over the southern margins of the Silurian reef is best explained as fissure production of Silurian oil.

The stratigraphy of the Silurian reservoir rocks and of the reef-capping Devonian limestones is presented in detail.

By January 1, 1947, there were 108 producing wells in the pool, with an average daily production of 3,200 barrels and a cumulative production of 2,528,000 barrels. The pool is still in the development stage.

INTRODUCTION

The Marine pool is in the eastern half of Madison County, Illinois, about 25 miles northeast of St. Louis, Missouri. Structurally, the pool is near the western border of the Eastern Interior basin, on the shelf between the Ozark uplift and the Illinois basin, where the Silurian and Ordovician strata dip eastward at an average rate of 50 feet per mile (Fig. 1). The shelf segment on which the Marine pool is located is characterized by pre-Mississippian oil production, in contrast to the deeper Illinois basin in which Mississippian beds contain the

[1] Published with permission of the chief of the Illinois State Geological Survey. Manuscript received, June 2, 1947.

[2] Illinois Geological Survey. The writer is indebted to E. P. DuBois, the co-author of the previous Marine pool report, to numerous company geologists who supplied vital information and sample sets and discussed freely the problems connected with the pool interpretation, and to several Survey members, in particular to Julian Smith of the Obering Oil Company, and Carl A. Bays, A. H. Bell, L. E. Workman, and D. H. Swann of the Survey. Donald B. Saxby assisted in the preparation of the structure maps and Jack A. Simon supplied the data for the structure maps of a Pennsylvanian horizon and the isopach maps of the beds between this horizon and the Lower Mississippian.

main reservoirs of oil accumulation. The pool is about 6 miles north of the St. Jacob pool, which is a "Trenton" producer.

The Marine pool is in T. 4 N., R. 6 W., covering parts of Secs. 3, 4, 5, 8, 9, 10, 11, 15, 16, and 17. The producing area is horseshoe-shaped. The pool was discovered partly on the basis of geophysical exploration and partly as an acreage deal. The discovery well, Eason-Rockhill-Obering's Mayer No. 1 in the SE. $\frac{1}{4}$, NW. $\frac{1}{4}$, SW. $\frac{1}{4}$, Sec. 15, T. 4 N., R. 6 W., completed in July, 1943, is at the southern border of the pool as now outlined. The well, drilled as a "Trenton" test to a depth of 2,590 feet, had oil showings in the upper 70 feet of the Niagaran strata, at depth of 1,750–1818 feet. The initial daily production

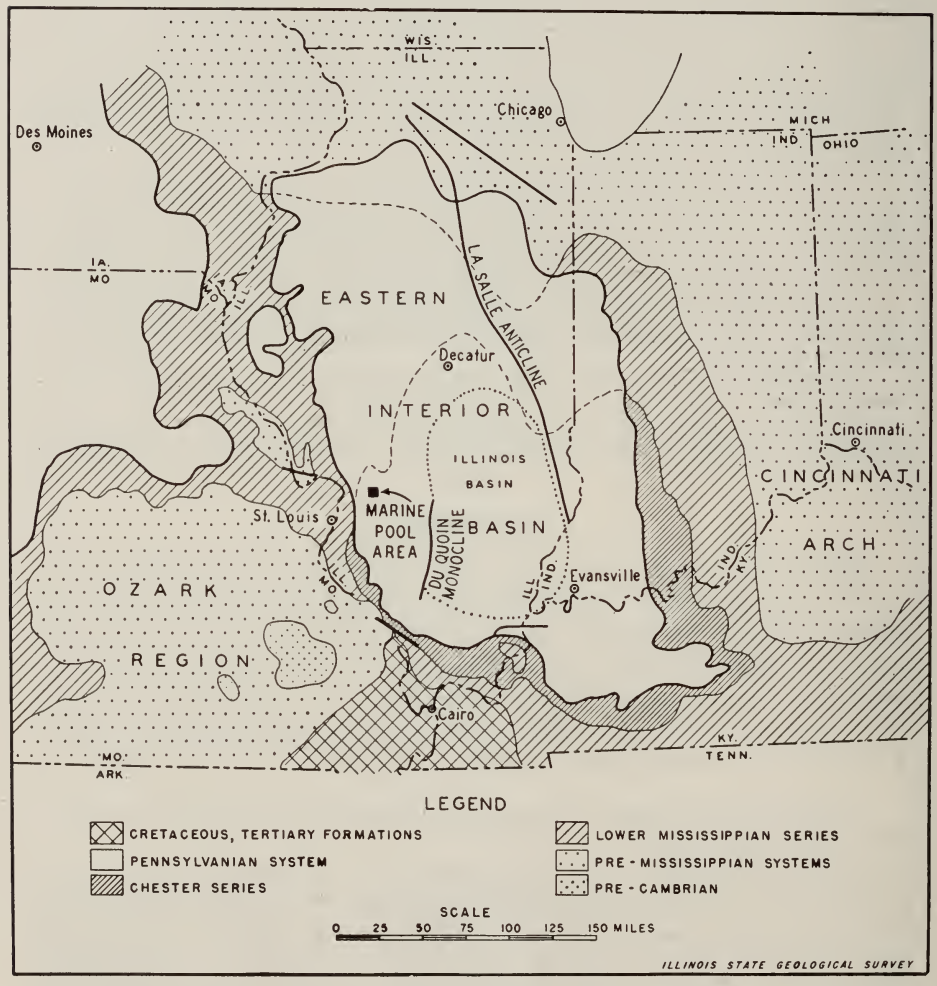

FIG. 1.—Index map showing location of Marine pool areas in relation to major regional structures.

was 14 barrels of oil and 3 barrels of water which was later increased by acidization. The development has proceeded gradually until at the end of 1946 there were about 108 producing wells, and 2,528,000 barrels of oil had been recovered. The pool is producing about 3,200 barrels of oil daily and has produced a large amount of water through its entire history.

The Marine pool is a stratigraphic-trap type of oil field in which the reservoir is a Niagaran reef. This was the first Niagaran reef recognized in Illinois outside the reef-bearing belts of Niagaran outcrops in the northern part of the state and is still the only Niagaran reef that produces commercial quantities of oil in Illinois.

This paper is based primarily on a previous report[3] which presented the basic data and interpretation of the reservoir as a Niagaran reef. Since the completion of the first report in 1945, the subsequent development of the pool and attempts at extension have established more precisely the areal extent, configuration, and the relief of the reef. Many additional data on the various Niagaran and Devonian lithologic types have become available, resulting in minor revisions of the previous interpretations. The present investigation has been extended to the townships bordering T. 4 N., R. 6 W., in which the Marine pool is located, allowing a clearer understanding of the regional Niagaran facies where not influenced by the reef, and of the structural relations of the Silurian and Ordovician strata.

STRATIGRAPHY

Stratigraphic résumé.—The bedrock surface in the Marine pool area is formed by the McLeansboro strata of the Pennsylvanian system and is generally covered by glacial drift except along a few creeks which cut into sandstones and shales close to the stratigraphic position of the Carlinville limestone. The Pennsylvanian strata comprise about 500 feet of sandstones, siltstones, shales, and a few limestone and coal beds. The principal markers are the prominent Piasa limestone at a depth of 200–300 feet in the pool area and the more persistent but less obvious Seahorne limestone intercalated between two thin coal beds about 200 feet below the Piasa limestone.

The Upper Mississippian Chester strata consist of about 200 feet of sandstones, shales, and limestones, the post-Chester erosion surface ordinarily lying on the Golconda or Cypress formation. The Lower Mississippian strata include about 40 feet of Ste. Genevieve limestone, 160 feet of St. Louis limestone, 120 feet of porous fossiliferous Salem limestone, and about 475 feet of Osage limestones, siltstones, and shales. The underlying Chouteau limestone averages 25 feet in thickness but locally it thins considerably and in a few wells it is missing. The black and brown New Albany shales of Kinderhook or Devonian age

[3] H. A. Lowenstam and E. P. DuBois, "Marine Pool, Madison County, Illinois," *Illinois Geol. Survey Rept. Inv. 114* (1946).

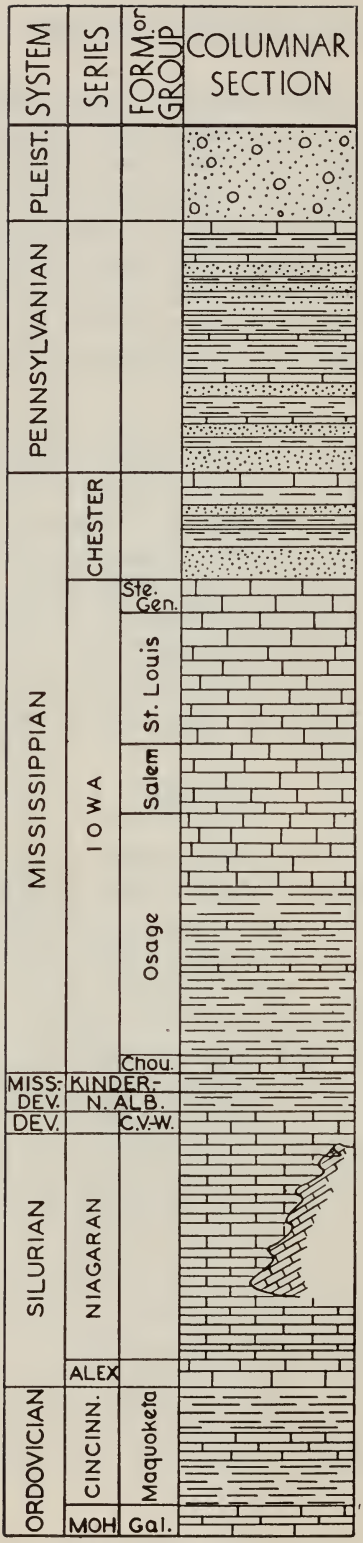

FIG. 2.—Sequence of strata in Marine pool area.

average 70 feet in thickness and are locally separated from the Chouteau limestone by 10 feet of green shales.

The Devonian strata are thin and consist of three formations: an upper unnamed siltstone unit, the Cedar Valley formation, and the Wapsipinicon formation. The Devonian thickens regionally northeast and thickens from 14 to 42 feet across the pool area (Fig. 3).

The Silurian system is represented by Niagaran and Alexandrian deposits. The Silurian strata thicken eastward across Marine township from 425 to 500 feet, conforming to the regional thickening of the Silurian toward the east at a rate of about 15 feet per mile (Fig. 4). In the pool area the Silurian strata increase abruptly in thickness (Fig. 4) and are estimated to reach a maximum of

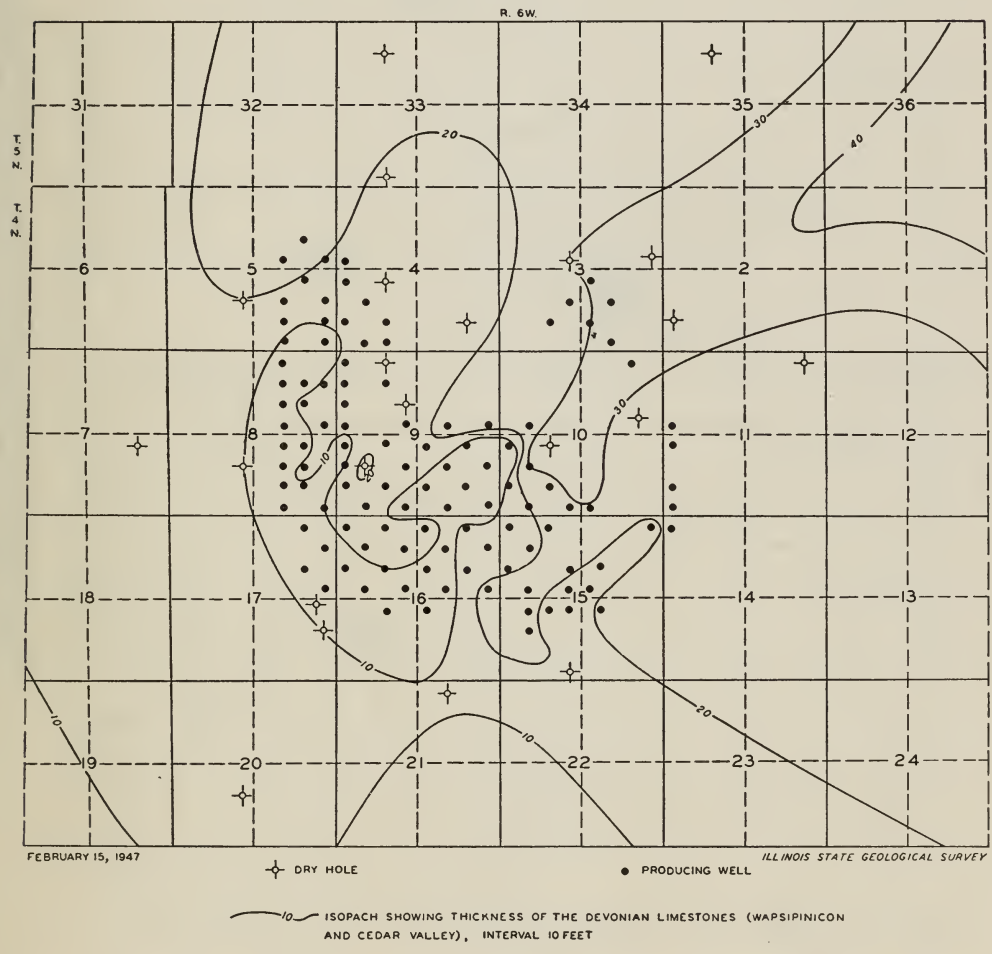

FIG. 3.—Isopach map of Devonian rocks below top of Cedar Valley formation in Marine pool area.

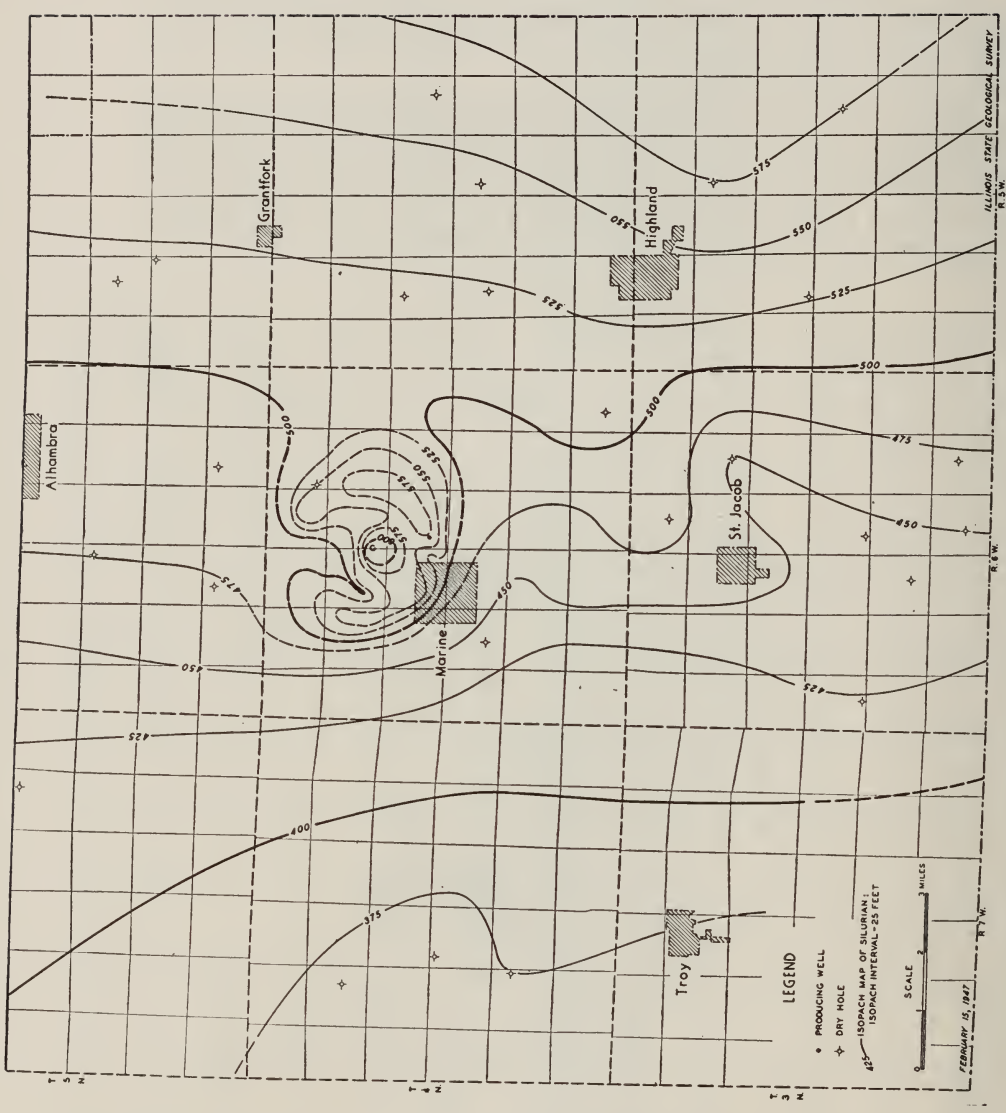

FIG. 4.—Regional isopach map of Silurian system. Inferred thicknesses in Marine reef area are based on isopach of Silurian-"Trenton" interval, minus Maquoketa thickness.

625 feet under the highest part of the pool. Both the regional and local thickening occur in the Niagaran, as the Alexandrian maintains a fairly constant average of about 45 feet in the area. Variations in thickness of the Niagaran are correlated with changes in facies. Three facies complexes are recognized. Two are regional and form a succession representing the normal Niagaran outside the pool area. A third and local facies is a reef complex which, in the pool area, replaces the upper regional facies entirely and the lower regional facies partially.

The Upper Ordovician is represented by 175 feet of Maquoketa shale and limestone which rest on approximately 550 feet of Middle Ordovician "Trenton" limestone. Only the upper 90–100 feet of "Trenton," belonging to the Galena (Kimmswick) and Plattin formations, has been penetrated by wells near Marine.

Devonian and Silurian stratigraphy.—The Silurian-Devonian stratigraphy is presented in greater detail to show the lithologic character of the reservoir and capping rocks and in particular to analyze the relationship between the reef and regional facies of the Niagaran in terms of the oil occurrence. The stratigraphic analyses of the cable-tool and rotary cuttings were greatly aided by one cable-tool and five rotary cores, augmented by additional core chips and shot samples. The section covered by the six cores extends from about 2 feet below the top of the Devonian to 68 feet below the top of the Niagaran. The Niagaran cores cover both reef and regional facies.

DEVONIAN SYSTEM

Introductory statement.—The Devonian deposits in the Marine pool area consist of three thin post-Onondagan formations separated from each other by erosional unconformities of different magnitude. The Wapsipinicon and Cedar Valley formations represent thin marginal deposits of the Iowa-Western Illinois facies province. The overlying unnamed formation may represent a marginal phase of some of the upper carbonate deposits in the thick sequence of limestone strata which comprise the Devonian in the deeper part of the Eastern Interior basin on the east. They are younger than the Cedar Valley strata in the Marine pool area but in the basin are now included in the Cedar Valley formation. The Devonian of the Marine pool area forms part of the thin, marginal section of a sedimentary wedge which thickens northeastward. The wedge border is located about 6 miles southwest of the pool area where the New Albany shale rests directly on truncated Niagaran strata. From there the Devonian thickens northeastward across Marine township at a rate of about 6 feet per mile, the rate increasing abruptly in the next township northeast to about 16 feet per mile. The Devonian thickness across the pool area increases irregularly northeast from 14 to 42 feet.

The wedge edge of the Devonian southwest of the pool marks the border of an Ozark lobe which extends into southern Illinois as far east as west-central

Washington County.[4] Within the lobe the New Albany shale generally rests on truncated Niagaran and Maquoketa strata but along the southeastern border it rests on lower Devonian deposits of the southern Illinois-eastern Missouri facies type which are not represented north of the lobe.

The development of the porous streaks in the Niagaran reef cap at the Marine pool is probably related to the marginal character of the thin Devonian deposits. The three converging unconformities separating the thin Devonian formations near the wedge edge suggest an accumulative effect of repeated weathering on the reef-capping limestone that, in conjunction with the fissure system, may account for the favorable conditions for oil accumulation in the reef cap.

Undifferentiated Devonian siltstones.—The highest Devonian deposits consist of 5–14 feet of calcareous, argillaceous siltstones which became sandy toward the base. This is commonly called "the detrital zone" by oil-company geologists.

The siltstones in the top part are grayish brown, argillaceous, glauconitic, and contain thin dolomite lenses. The lower siltstones are dark brown, more shaly, and conspicuously sandy and pyritic. The sand is medium- to coarse-grained, frosted, and occurs concentrated in thin inclined lenses and as individual grains scattered through the siltstone. The sand increases toward the base, where it is commonly cemented by pyrite and less commonly by carbonate. The sand grains, tightly cemented by pyrite, were found to be a good marker of the formational base, even in poor rotary samples. Gray to brownish gray chert occurs in places at the very base of the formation. The chert represents a silicified coquina of sponge spicules, ostracods, tentaculites, and echinoderm fragments which are sorted by size.

An intraformational conglomerate separates the two siltstone units in the only core in which the contact zone was recovered. Gradation from one lithologic type into the other is indicated, however, by the interlensing of the two types over a considerable distance from the conglomeratic zone. The undifferentiated Devonian siltstone is unconformable on the Cedar Valley limestone. The contact is sharp and irregular with Cedar Valley pebbles occurring in the basal 4 inches of the siltstone in the core of the Ohio Oil Company-Grotefendt's I. C. R. R. Community No. 1 pool well in the SE. $\frac{1}{4}$, SW. $\frac{1}{4}$, NE. $\frac{1}{4}$, Sec. 9. Ostracods from the basal chert of the siltstone unit indicate a post-Cedar Valley pre-Cerro Gordo age.[5]

Cedar Valley formation.—The Cedar Valley formation is represented by shallow-water deposits which are characterized by rapid lateral and vertical changes in lithologic composition. There is gradation all the way from slightly

[4] The extent of the pre-New Albany unconformity here is based on information supplied by L. E. Workman and revises slightly the outlines shown in *Illinois Geol. Survey Bull. 68*, p. 196, Fig. 47.

[5] C. L. Cooper, personal communication.

argillaceous limestones to calcareous sandstone, the common type being a sandy argillaceous limestone with discontinuous laminae of sandy shale. The limestones are commonly mottled dark gray and brown and represent, as a rule, coarse coquinas or semi-coquinas of skeletal débris. The coquina constituents consist predominately of dissociated crinoidal remains which are associated with fragmentary stromatoporoids, colonial corals, brachiopods, and bryozoans. The common constituents of the coquinas are robust, rough-water forms. Partial replacement by dolomite, secondary silica, pyrite, and glauconite is common. The interstitial spaces of the coquina are commonly occupied by medium- to coarse-grained sand grains, secondary calcite, and brown to gray clay and silt, and in places by pyrite, glauconite, and fine brown dolomite. The mottled color of the limestones is produced by the selectively pyritized bryozoans and the interstitial clastics. The clastic laminae range from shales to argillaceous sandstones and consist of the same constituents found in the interstitial spaces of the coquina.

Pure carbonate sediments in the Cedar Valley are less common and differ in that interstitial spaces between coquina fragments are filled with fine-grained limestone and some secondary calcite, whereas clastics are confined to thin wavy laminae which produce a nodular appearance in cores.

The uncommon calcareous or dolomitic sandstones in the Cedar Valley are medium- to coarse-grained, cemented by a fine limestone or dolomite matrix, and contain small amounts of crinoidal débris.

Conglomeratic zones are locally developed near the top and bottom of the formation. The Cedar Valley lies unconformably below the undifferentiated Devonian siltstones and rests unconformably on the Wapsipinicon formation. The basal unconformity appears to be of considerable magnitude, as an extensive fissure system (discussed separately) extends from it through the Wapsipinicon into the upper Niagaran beds. The Cedar Valley formation thickens progressively from 2 to 16 feet northwestward across the pool area with no recognizable thinning over the pool structure.

Scattered along the west side of the pool is a series of lenticular sand bodies of limited areal extent whose stratigraphic relationship is still uncertain. The sand bodies are known in three separate areas. They consist of 2–4 feet of medium to coarse, frosted sand, commonly unconsolidated but rarely cemented with calcite. This is the "Hardin sand" of the oil-company geologists; it is a fissure producer of Silurian oil along the southwestern border of the pool. The areal extent of the sand bodies has not been fully defined, due in two cases to their location at the pool edge and in the third case to the lack of samples from certain wells. Continuity over at least 1,320 feet was established for the northernmost lens by its occurrence in the two adjacent wells in the E. $\frac{1}{2}$, SW. $\frac{1}{4}$, SE. $\frac{1}{4}$, Sec. 5, where the sand rests on Cedar Valley limestone. The producing sand at the southwestern border of the pool appears to be larger, as it has been reported in four wells, two in the NE. $\frac{1}{4}$, NE. $\frac{1}{4}$, Sec. 17 and the adjacent wells on the

south and northwest. Continuity over at least 2,000 feet has been established through samples from three adjoining wells, two of which have been deepened recently, showing the sand resting in one well on Wapsipinicon limestones and in the other directly on Silurian reef rock. The sand rests on Wapsipinicon limestone in the third lens in the NW. $\frac{1}{4}$, SE. $\frac{1}{4}$, NW. $\frac{1}{4}$, Sec. 16. In all occurrences the sands are overlain by the undifferentiated Devonian siltstones.

The sand in the base of the undifferentiated Devonian siltstones is also of the Cedar Valley type, and is probably derived from erosion of the underlying Cedar Valley. The lenticular sand bodies could thus be interpreted as localized concentrations of reworked Cedar Valley sand at the base of the succeeding formation. This interpretation would imply a post-Cedar Valley unconformity that cuts in places through the Cedar Valley and through the Wapsipinicon formations down to the Silurian, unless the Wapsipinicon had been already removed during the pre-Cedar Valley erosion period. Because of the converging Devonian unconformities in the area under consideration, the excess in erosion required would be only about 10 feet (Fig. 3). Arguments against this interpretation are based on the fact that the sand concentrations observed within the basal Devonian siltstones do not even approach comparable thicknesses and that the sands are everywhere highly cemented by pyrite or calcite. The isopach map of the Cedar Valley formation further shows progressive thinning to the southwest across the pool area (Fig. 5). Although generally less than 10 feet in thickness, the formation appears to be persistent, save for two of the occurrences of the disputed sand bodies.

An alternative interpretation is that the sand bodies represent a sandy phase of the Cedar Valley which varies in lithologic composition from a slightly argillaceous limestone to a calcareous sandstone. The development of a pure sand phase replacing all or part of the formation is feasible, considering the extreme width of lithologic variation. This view is further supported by the restricted occurrences of the sand bodies on the west side of the field where they are roughly aligned with similar bodies near the northeastern border of the St. Jacobs pool about 6 miles south. This alignment roughly parallels the border of the Ozark prong in which Devonian deposits are missing, implying a series of sand bars which either bordered a shoal or lay off-shore from the strand line of the shallow Cedar Valley sea. If this interpretation is correct, the sand bodies represent a Cedar Valley phase related to the Hoing sand in the Colmar-Plymouth field.[6] This interpretation is favored by the writer as it also agrees with the thickness relations of the Cedar Valley limestone over the pool area (Fig. 5) which indicate rather uniform erosion surfaces both below and above the formation.

WAPSIPINICON FORMATION

The Wapsipinicon formation ranges in thickness from 2 to 24 feet in the area and is absent in one pool well. The formation is characterized by two distinct

[6] L. E. Workman, "Subsurface Geology of the Devonian System in Illinois," *Illinois Geol. Survey Bull. 68* (1944), p. 197.

lithologic types, a buff to brown dense micro-crystalline limestone and a brown or brownish gray fine-grained dolomite. The limestones, as a rule, form the top part but may extend to the base of the sequence and contain isolated medium to coarse sand grains and variable amounts of chert. Sandy conglomeratic zones are locally developed. The dolomites which commonly form the basal part of the section are porous, but not permeable, and are commonly conspicuously silty and locally sandy. Transitional dolomitic limestones may occur at variable positions in the Wapsipinicon. The basal Wapsipinicon dolomites commonly include considerable amounts of reworked Niagaran material. Over the pool area, this reworked phase is commonly coarse-grained white to cream-colored reef detritus in a brownish gray silty sandy matrix. Outside the pool border, but close to the pool, the basal Wapsipinicon deposits appear to grade through strata no more than two feet thick into the underlying normal Niagaran strata

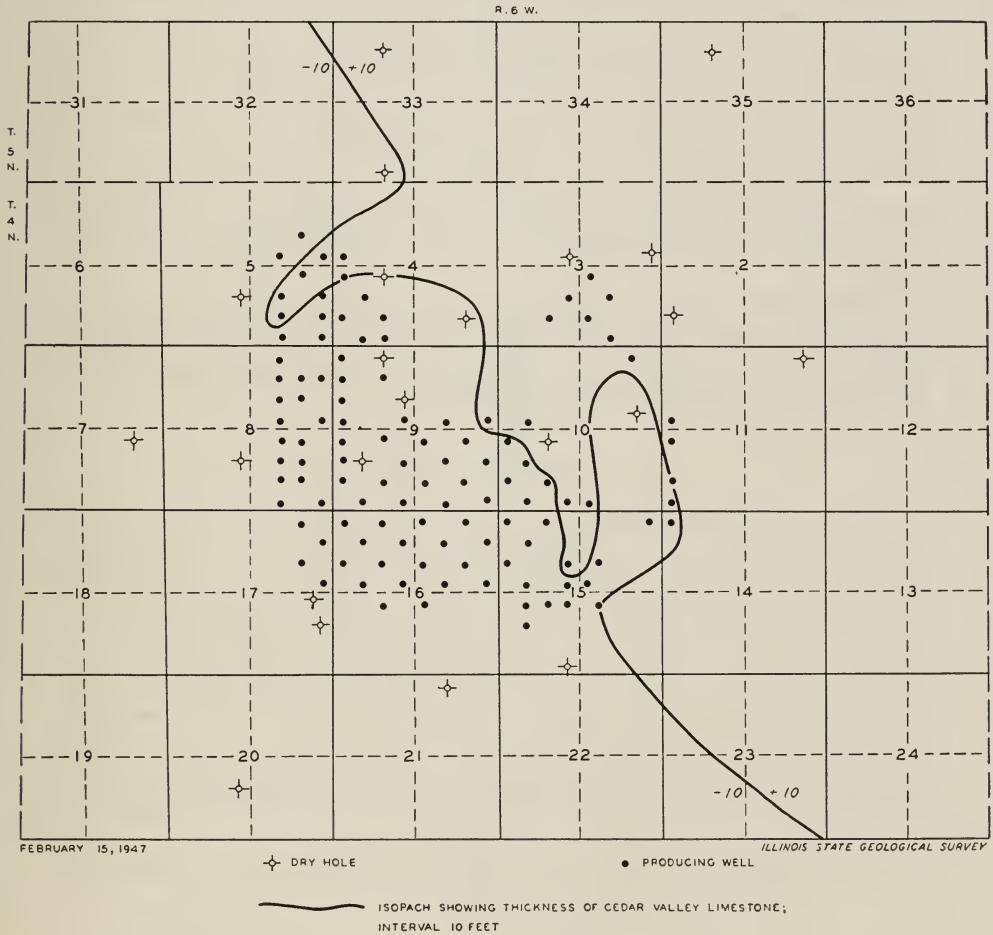

FIG. 5.—Isopach map of Cedar Valley limestone.

that consist of light gray to buff silty fine-grained dolomites. The reference of these transitional strata to the Wapsipinicon is based on the presence of medium to coarse sand grains and brown coloration, both of which are foreign to the Niagaran sediments of the area under consideration.

The Wapsipinicon formation is unconformable with the overlying and underlying formations. In contrast to the practically level erosion surface at the top of the formation (Fig. 5), the unconformity at the base of the formation is marked by low topographic relief whose features are fairly well defined in the pool area and its vicinity. The isopach pattern of the Wapsipinicon formation (Fig. 6) implies that the western half of the reef area and the highest tops of the fore-reefs on the southeast stood slightly less than 10 feet above the general pre-Wapsipinicon surface; that furthermore this surface was traversed by a northeast-heading valley system whose headwaters, although not yet precisely definable, were in the direction of the Ozark-flanking lobe. The course of the main channel in the reef area and the entire course of its western tributary are closely controlled by the reef topography in general and by the reef core locations in particular. The drainage pattern is largely superimposed on topographic reef depressions, with the exception of its course in the eastern fore-reef area where the main channel, instead of being deflected around the northernmost fore-reef, cuts through a low sag just south of it. The cutting of the drainage course appears to have been facilitated by the reef detritus and possibly reef-flank material that were less resistant to weathering than the compact reef core rock.

The present known variations in the thickness of the Wapsipinicon formation have been established by marginal drilling, and this later information invalidates the statement made by the writer in the earlier report that the Wapsipinicon is uniform in thickness.[7]

FISSURE SYSTEM

A very closely spaced network of fissures enlarged by solution extends from the post-Wapsipinicon surface not only through the Wapsipinicon deposits, but at least 50 feet into the underlying Niagaran deposits. Practically all wells in the pool area cut fissures, and most of the wells cut several of them. In the Niagaran deposits, the pure carbonate rocks of the reef-capping detritus are very much more intensely fissured than are the silty argillaceous carbonate rocks of the normal facies outside the pool area. Fissures seen in cores have a maximum diameter of 2 inches and interconnect joints, bedding planes, vugs, and stylolitic seams (Fig. 12a). Cable-tool samples obtained in deepening wells indicate that fissures several feet in diameter are common. The walls of the fissures are

[7] H. A. Lowenstam and E. P. DuBois, "Marine Pool, Madison County," *Illinois Geol. Survey Rept. Inv. 114* (1946), p. 29.

commonly smooth or striated in slickolite[8] fashion, indicating that movement of the fill accompanied the solution. These fissures are tightly filled with sand or clay and may enclose wall-rock fragments with solution-resorbed margins. Clay is the fill in the narrowest fissures. As the fissures increase in diameter, sand is associated with the clay in increased proportion. The widest fissures are packed with calcareous sand that contains clay only along the fissure border and around fragments of wall rock. The sand is commonly medium to coarse, rarely fine, well rounded and frosted. The clays are light green, gray, and white. The clays and the sands (to a lesser extent) are pyritic.

[8] J. H Bretz, "Solution Cavities in the Joliet Limestone of Northeastern Illinois," *Jour. Geol.*, Vol. 48 (1940), p. 352.

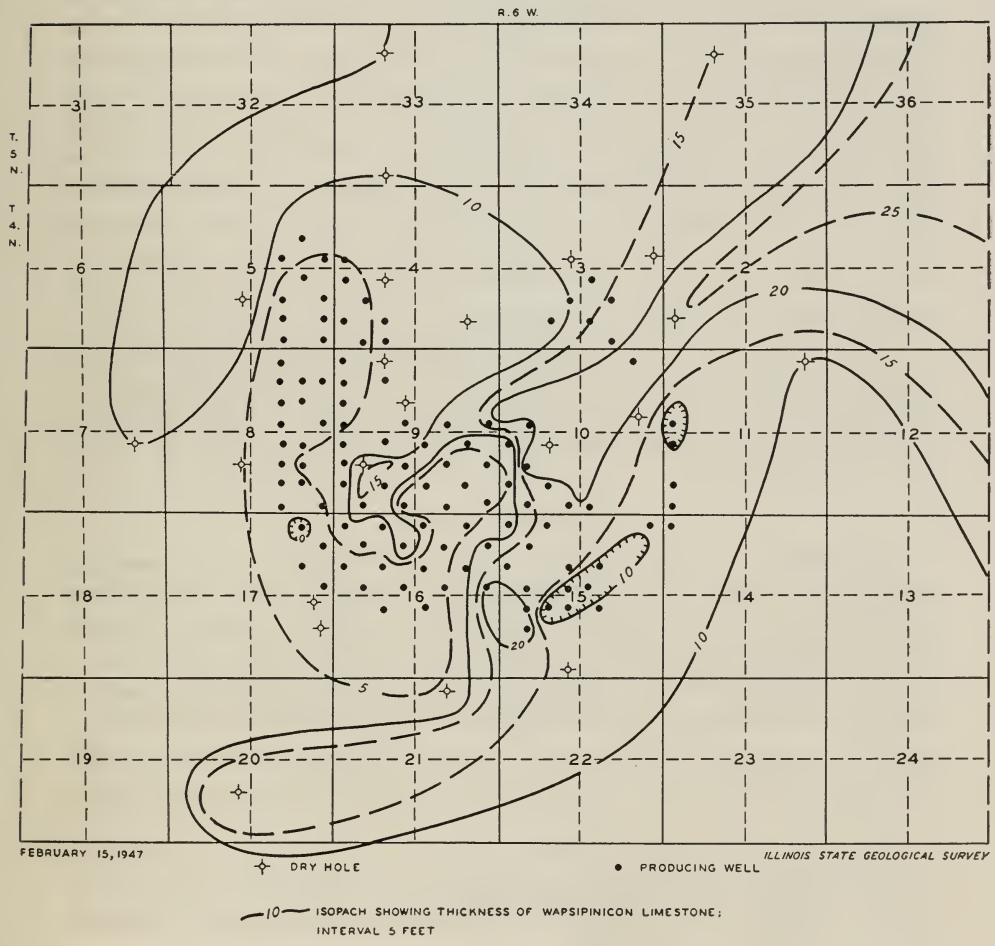

FIG. 6.—Isopach map of Wapsipinicon formation.

Evidence of secondary porosity zones in the wall rock following the border of the fissures has been observed in the Niagaran reef-capping detritus in cores and shot samples. The interstitial spaces of the coquina, which are normally filled with secondary calcite are partly open or filled with a porous chalky residue. These secondary porosity zones probably extend horizontally at various levels over short distances into the reef cap to form the porous streaks of the producing zones and vertically into the reef core.

The fissure system was developed during the post-Wapsipinicon-pre-Cedar Valley erosional interval. If the solution phenomena are the product of groundwater solution, it appears likely that the area stood at least 50 feet above local base-level. Surface connections are required to account for the infiltration of the fissure fill. The absence of clay in the Wapsipinicon and Niagaran reef sediments requires an outside source. It is interesting to note that in the central area of the Ozark-flanking lobe at the southwest the New Albany shale rests on Maquoketa shale. The Maquoketa and the Niagaran could have been the sources of the clay fill, provided that they were already exposed in the time interval under discussion. The tentative suggestion of a relationship between the clay and the Independence shale of Iowa expressed in the previous report[9] is less probable, particularly since the age of the Independence shale has become a matter of dispute.[10] The sand of the fissure fill is of the types found in the capping Cedar Valley formation and in the Wapsipinicon limestone. The Wapsipinicon does not appear sandy enough to provide the amount of sand in the fissures. Probably a limited amount of the sand came from eroded Wapsipinicon deposits. The source of the bulk of the sand is still unaccounted for, but the deposits may well be related to the Hoing sand in the basal Cedar Valley at the Colmar-Plymouth oil field.[11] This view, if verified, would support the Cedar Valley age of the lenticular sand bodies.

SILURIAN SYSTEM

The Silurian system in the area consists of Niagaran and Alexandrian deposits. The Silurian strata thicken regionally eastward across the Madison County area, as shown in Figure 4, from 360 to 580 feet, or about 15 feet per mile. The Niagaran strata thicken at the same rate across this area from 320 to 530 feet. This thickening occurs entirely in the upper regional facies complex, facies B of the Niagaran. The basal regional Niagaran facies complex, facies A, and the Alexandrian maintain a fairly constant thickness in the region. In the pool area, and confined to it (T. 4 N., R. 6 W.), facies B and at least the upper

[9] H. A. Lowenstam and E. P. DuBois, *op. cit.*, p. 18.

[10] G. A. Cooper, "Correlation of the Devonian Sedimentary Formations of North America," *Bull. Geol. Soc. America*, Vol. 53 (1942), p. 1766.
K. A. Stainbrook, "The Stratigraphy of the Independence Shale of Iowa," *Amer. Jour. Sci.*, Vol. 243 (1945), pp. 67–83; 138–58.

[11] L. E. Workman, "Subsurface Geology of the Devonian System in Illinois," *Illinois Geol. Survey Bull. 68* (1944), p. 197.

third of the underlying facies A in the Niagaran are replaced by a reef, that covers approximately 6 square miles. The reef is expressed on the Silurian isopach map (Fig. 4) as an insular area of abrupt thickening of the Niagaran strata and thus is shown as a thickness anomaly. Figures on the Silurian thicknesses in the reef area are confined to two wells that are both located near the thinned reef border: Eason-Rockhill—Obering's Meyer No. 1 in the SE. ¼, NW. ¼, SW. ¼, Sec. 15, and the Ryan Oil Company's Kesner No. 1 in the NW. ¼, SW. ¼, SW. ¼, Sec. 2, where the reef-bearing Niagaran strata attain thicknesses of 515 and 490 feet, respectively, and the entire Silurian reaches thicknesses of 570 and 545 feet. These thicknesses are 65–90 feet greater than would be expected at these localities according to the regional trend of thickening. The maximum excess thickness of the Niagaran at the reef center must be of the order of 150 feet over the normal regional thickness, thus making the thicknesses of the entire Silurian about 625 feet. This figure, as well as the Silurian thickness in the entire reef area on the Silurian isopach map (Fig. 4), is inferred from the Galena (Kimmswick) "Trenton" structure (Fig. 7), the Silurian structure (Fig. 8), and the average Maquoketa thickness. The actual reef thickness in the two marginal wells is 350 and 425 feet, and in the reef center it is estimated to amount to 475 feet but may reach 510 feet.

NIAGARAN

The Niagaran deposits outside the reef area consist of two regional facies complexes which overlap from opposite directions.

The basal facies complex, here called facies A,[12] is represented by types of sediments which are characteristic of the Bainbridge formation of the Ozark border in southeastern Missouri and southwestern Illinois. In the subsurface of Illinois this Bainbridge type of sediment forms a wedge that thickens slightly a short distance away from the Ozark border to a maximum of about 210 feet but from there it thins radially through interfingering with the overlapping facies wedge until it is less than 30 feet thick at the outcrops in northeastern Illinois where it forms the basal Joliet. This facies complex finally wedges out entirely at a distance varying from 200 to 450 miles from the Ozark border. In the Madison County area the thickness of this facies complex is fairly uniform beyond a radius of about 2 miles from the reef, ranging from 140 to 180 feet but averaging 150 feet.

The upper facies complex, facies B, embraces distinct sedimentary types characteristic of the northern Niagaran outcrop belts around the Michigan basin and in northwestern Illinois and adjacent eastern Iowa. This northern facies type, overlapping and interfingering with facies A, progressively thins southwest and wedges out entirely at the Ozark border. The facies complex

[12] The facies complex here signified as A and B, will be named after a regional study to delineate them areally and stratigraphically is completed.

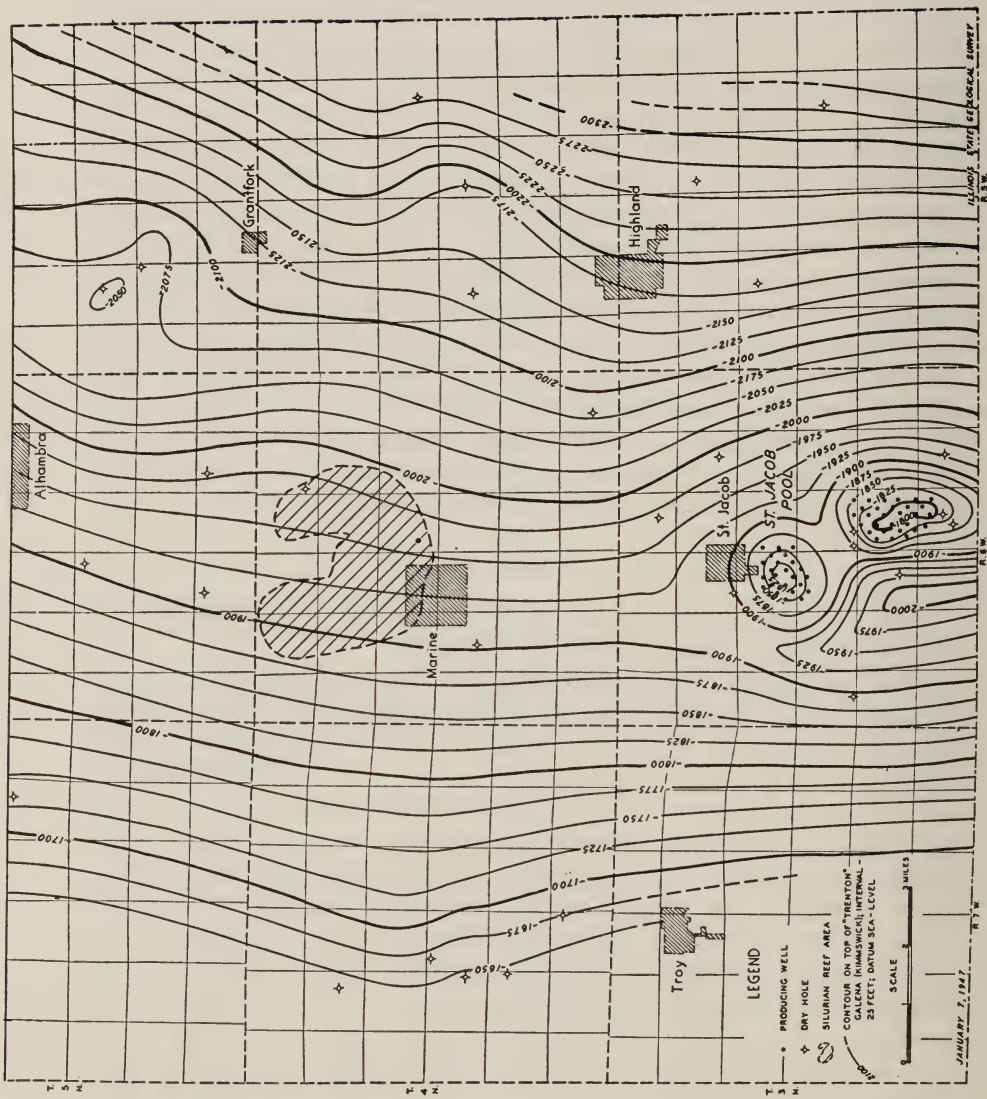

FIG. 7.—Map showing regional structure of top of Galena (Kimmswick) "Trenton."

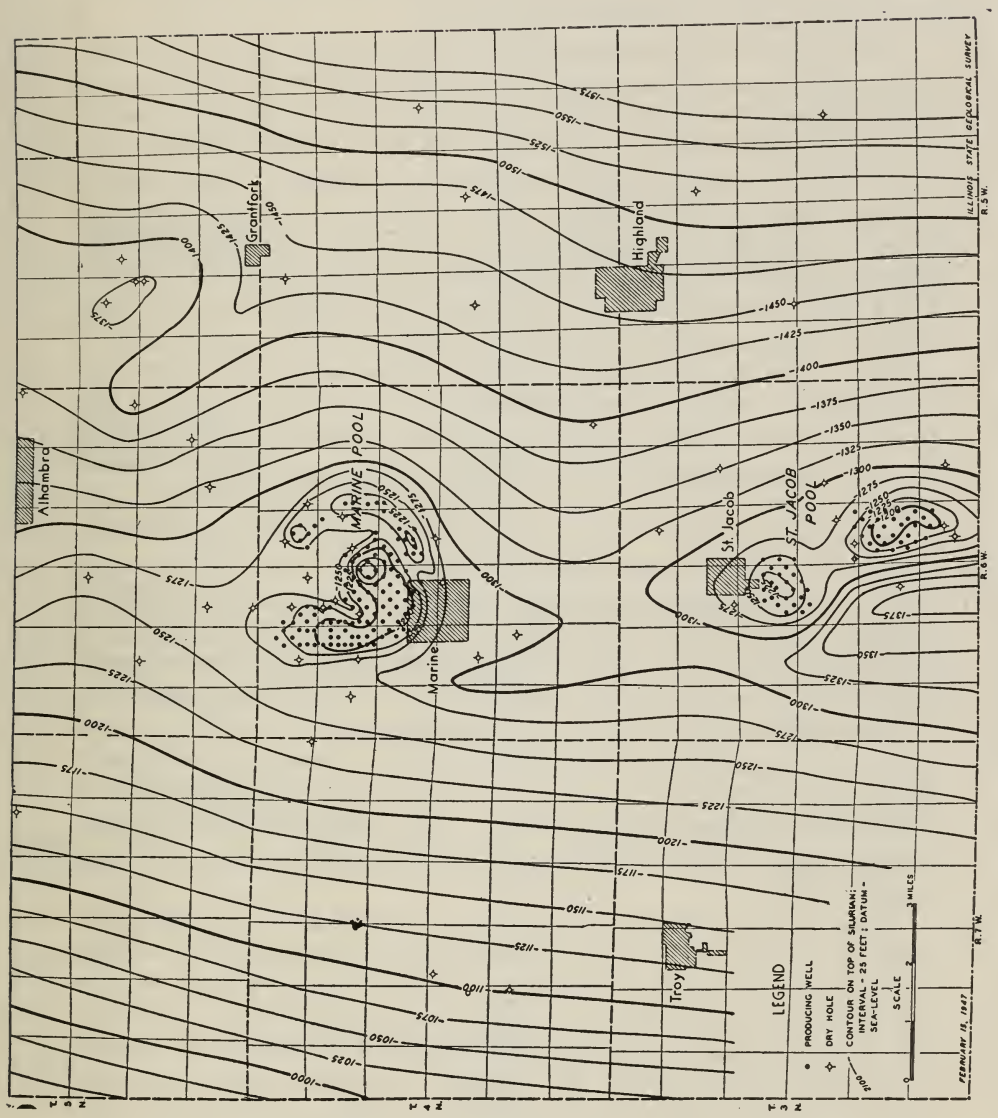

FIG. 8.—Map showing regional structure of top of Silurian system.

thins westward across the Marine pool area from 380 to 170 feet, clearly expressing its wedge character. The rate of thinning is here accentuated, however, by pre-Wapsipinicon erosion which beveled the Niagaran sediments that had been tilted eastward in post-Niagaran time.

In the pool area the normal sediments of these regional facies (excepting the basal 90 feet of facies A) are replaced by a reef facies that covers 6 square miles. Because of the shallow depth of the oil-producing strata in the top portion of the reef complex, our present knowledge of its character is in large part confined to the top 2–50 feet. Because of the occurrence of a widespread detrital mantle formed on top of the reef during the reef-terminating phase, few wells penetrate the reef structure proper. Only a very few of the shallow wells extend into reef-flank portions, and only one, the Sohio's Keown No. 3 in the NW. $\frac{1}{4}$, SE. $\frac{1}{4}$, NE. $\frac{1}{4}$, Sec. 17, penetrated 7 feet of reef-core rock, the detrital mantle being absent at this point. Information on the deeper parts of the reef complex is confined to two deep tests that are located on the eastern reef border, the Eason-Rockhill—Obering's Meyer well No. 1 in the SE. $\frac{1}{4}$, NW. $\frac{1}{4}$, SW. $\frac{1}{4}$, Sec. 15, and the Ryan Oil Company's Kesner well No. 1 in the NW. $\frac{1}{4}$, SW. $\frac{1}{4}$, SW. $\frac{1}{4}$, Sec. 2. The Eason-Rockhill—Obering's Meyer well No. 1 cut 425 feet of reef deposits that consist in descending order of 30 feet of reef-capping detritus, 30 feet of fore-reef core and flank rocks, 340 feet of reef-flank rock, and 25 feet of fore-reef core rock. The Ryan Oil Company's Kesner well No. 1, for which only a generalized company sample log and electric log were available, cut about 25 feet of reef-capping detritus and at least 250 feet of reef-flank rock. The underlying 140 feet of limestone represent either additional reef-flank deposits (an interpretation adopted in the electric-log cross section, Fig. 9, well E), or more probably an interfingering of the reef flank with the normal regional facies B sediments that incorporated appreciable amounts of reef detritus (the interpretation adopted in the geologic cross section, Fig. 10, well I). The latter interpretation is based on the reported occurrence of shale partings, foreign to the reef. On the main reef only the margin of the core has been penetrated and that only in the one well already noted.

In general, the components of the Marine reef structure correspond essentially with those of the outcropping Niagaran reefs, differing only in showing less dolomitization and in the development of the detrital reef cap. A reef core that is flanked by detrital fans on which small fore-reefs were periodically developed, only to be overwhelmed and buried in turn by reef wastage, has been recognized in both subsurface and outcrops. The detritus that blankets the entire reef complex and extends irregularly into the adjacent border area, represents a terminal phase of deposition that has not been described for the outcropping reefs. The flank deposits and the detrital cap are similar in that they are both rough-water derivatives of broken organic wastage from the reef, but they differ in that one was deposited during the growth and the other during terminal phases of reef development.

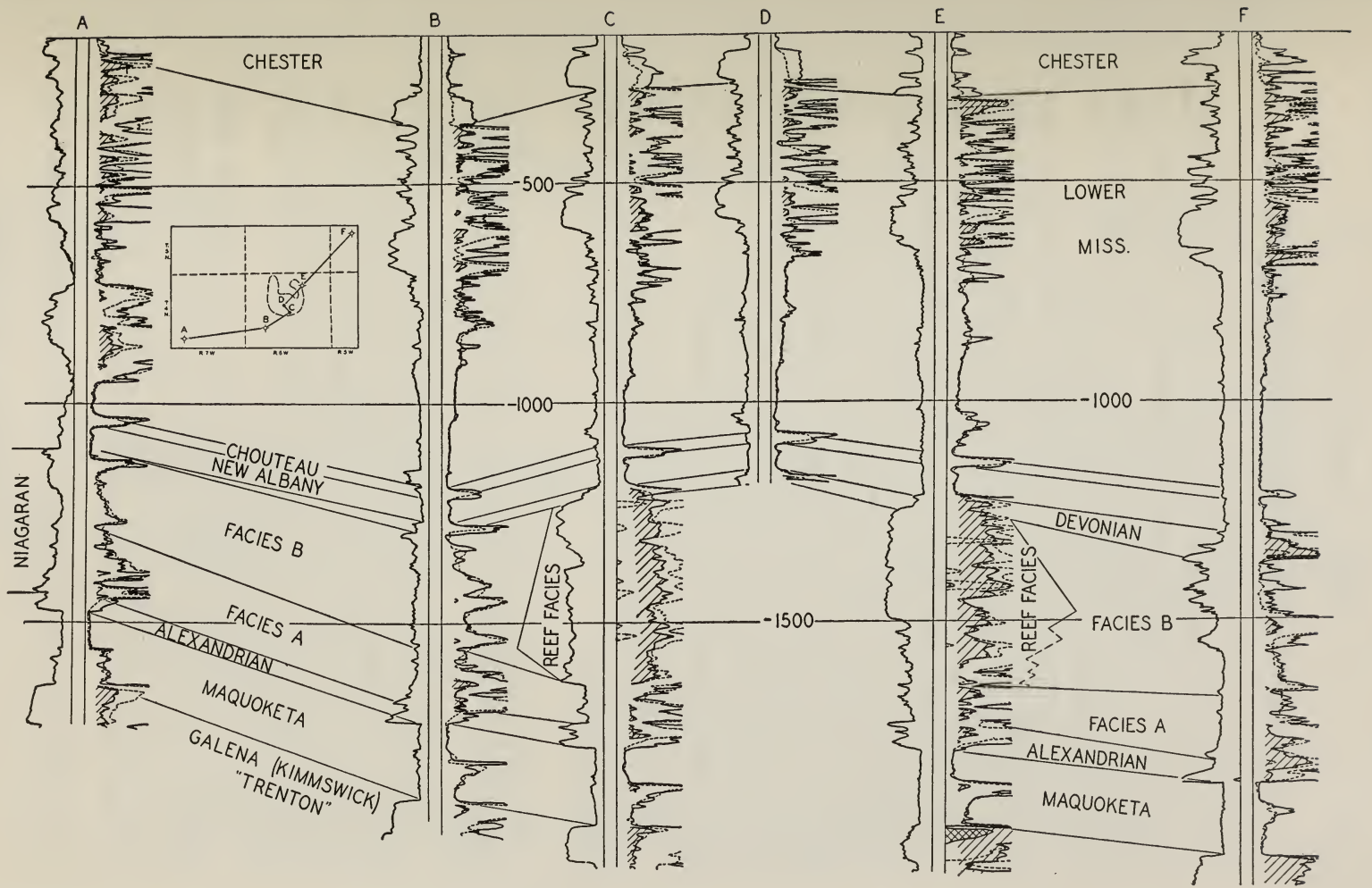

FIG. 9.—Regional southwest-northeast electric-log cross section showing relationship of Marine reef to regional facies complexes in Niagaran and to overlying and underlying deposits.

The structure on top of the Silurian in the pool area (Fig. 11) is essentially an expression of the reef topography and distribution and was produced by differential compaction. The surface of the reef complex generally lies between the −1,230 and −1,260 contours. The lower part of the slope was produced by reef outwash on the reef-bordering sediments and possibly by protruding reef-flank wedges (Fig. 10). Wells that penetrate below −1,260 enter sediments of the normal regional facies, but within a 2-mile radius from the reef the well samples include recognizable reef-derived detritus in small quantities.

The reef complex is horseshoe-shaped, enclosing a semi-lagoon on the north. The topographic relief indicates a composite reef. The western two-thirds of the reef complex appear to represent a reef body which is itself horseshoe-shaped, but with the open side facing northeast. The eastern third of the reef complex consists of a semicircular fore-reef ridge, which is a composite of the steeply dipping flank of the main reef that was raised through the periodic development of individual fore-reefs (Fig. 10, cross section). At least two fore-reefs are expressed topographically, and a deeply buried one was encountered at the reef-flank base in the discovery well. Although the major salients of the reef topography are recognizable on the Silurian surface, there is little doubt that the combined effects of the detrital mantle, of the pre-Wapsipinicon erosion, and of later structural movements, have slightly altered the topography. The detrital mantle tended to equalize the relief; the erosion tended to excavate but at the same time modify the original reef topography.

In the following description of the Niagaran facies, the regional facies are described first, followed by the reef facies, and concluded by the facies relations along the reef border.

FACIES A

The facies A complex is represented by a basal 60 feet composed chiefly of limestones and an upper 90 feet consisting largely of calcareous siltstones and shales.

The basal limestones are fine- to coarse-grained, white to buff, red- and pink-mottled or homogeneously red, and contain some red, purple, or green shaly or silty clastics, commonly concentrated in thin beds or laminae. The limestones are rarely partially dolomitized. The red coloration and the coarse grain of the limestones are practically confined to crinoidal remains demonstrating that the intensity of red coloration and the coarseness of the limestones are primarily a function of crinoidal density in the sediments.

These basal limestones are similarly represented in outcrops in the basal Bainbridge formation of southwestern Illinois and southeastern Missouri, reported by Ball[13] and in the pink crinoidal top member of the Chimney Hill formation in the western Arbuckle Mountains of Oklahoma, where they form the basal Niagaran deposits. These sediments represent a marginal phase of a

[13] J. R. Ball, "Some Silurian Correlations in Lower Mississippi Drainage Basin," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 26 (1942), p. 3.

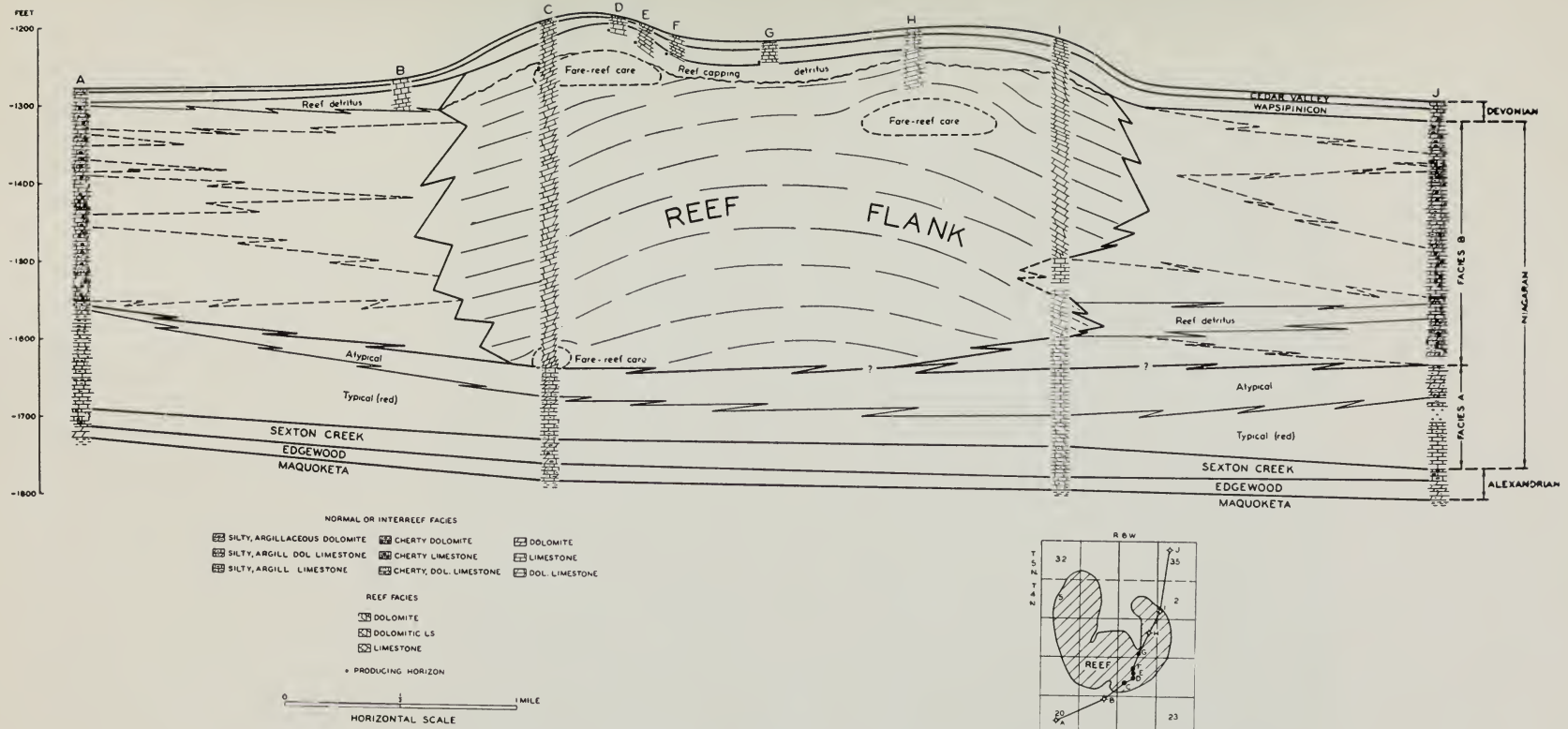

FIG. 10.—Cross section of Devonian and Silurian deposits, showing Marine reef and bordering zone of reef control.

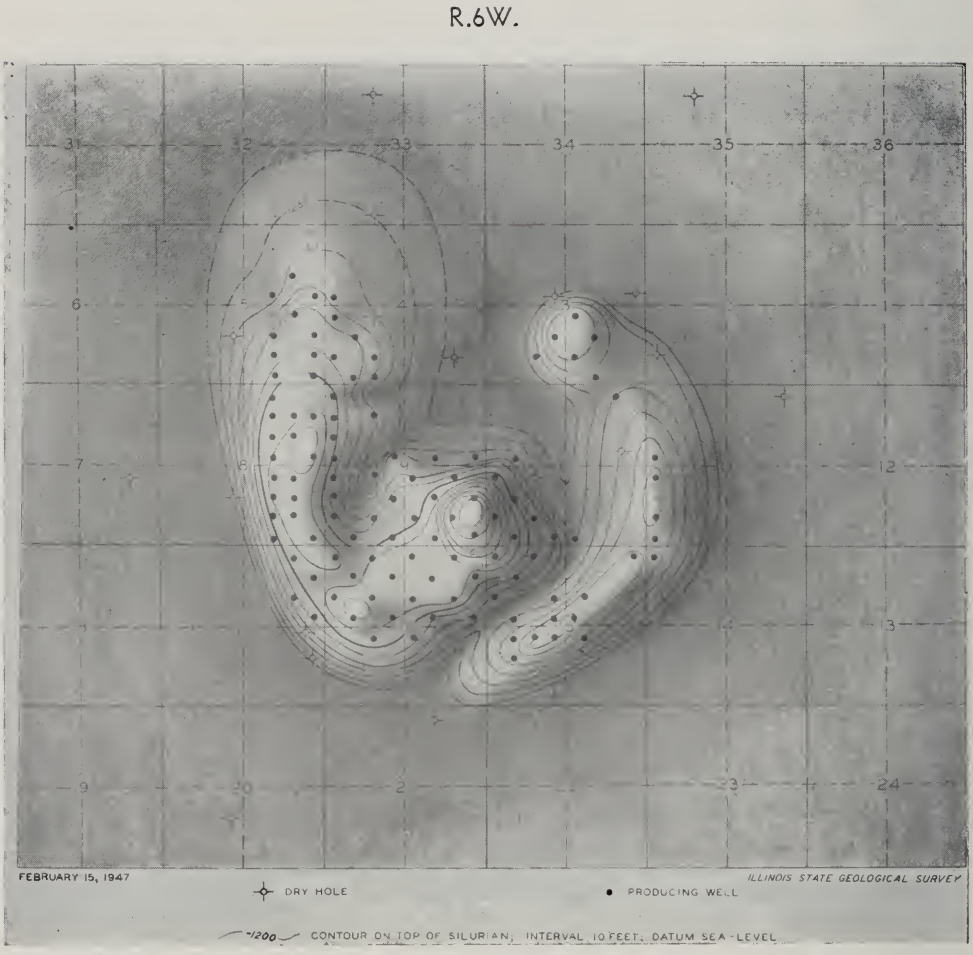

FIG. 11.—Shadowgraphic diagram showing relief of Marine reef complex on top of Silurian surface.

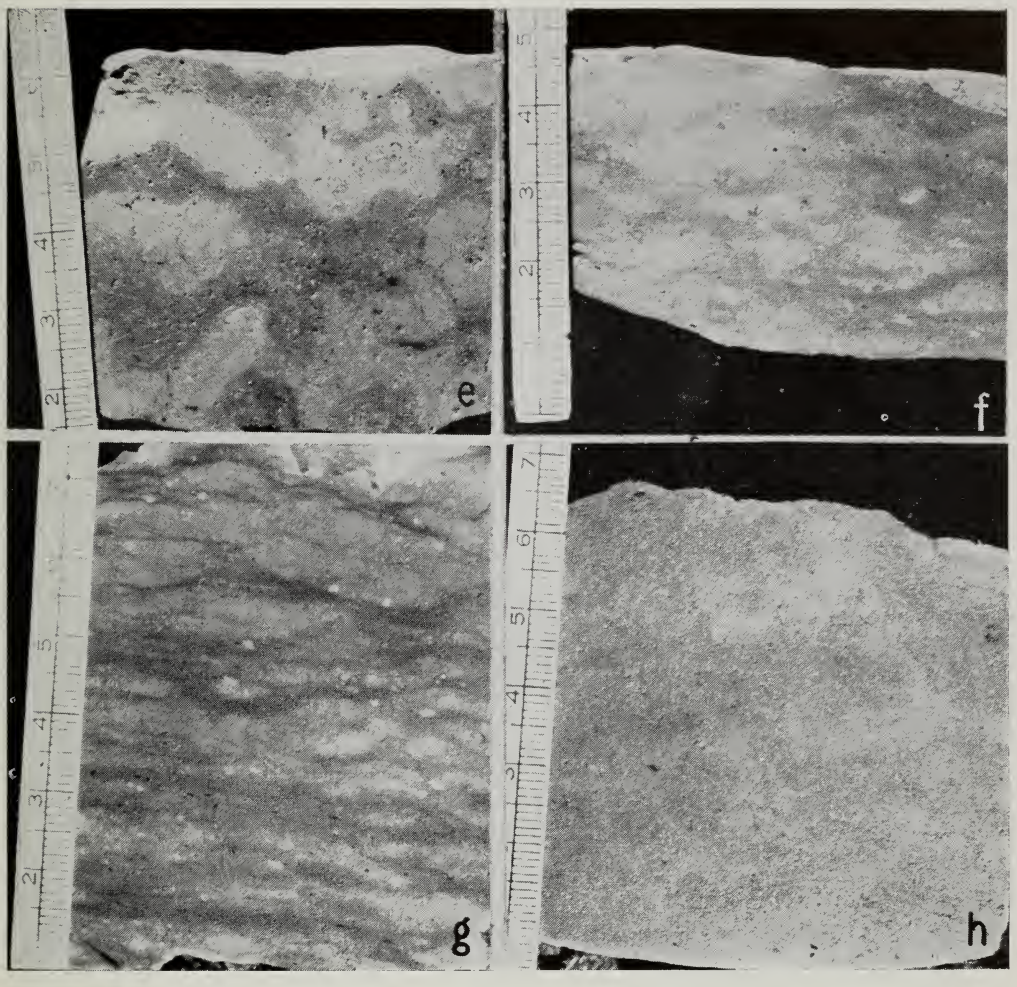

FIG. 12A.—Lithologic character of Niagaran reef deposits: (e–h) lithologic characters of regional or normal facies B (Niagaran). (Scales are in centimeters.)

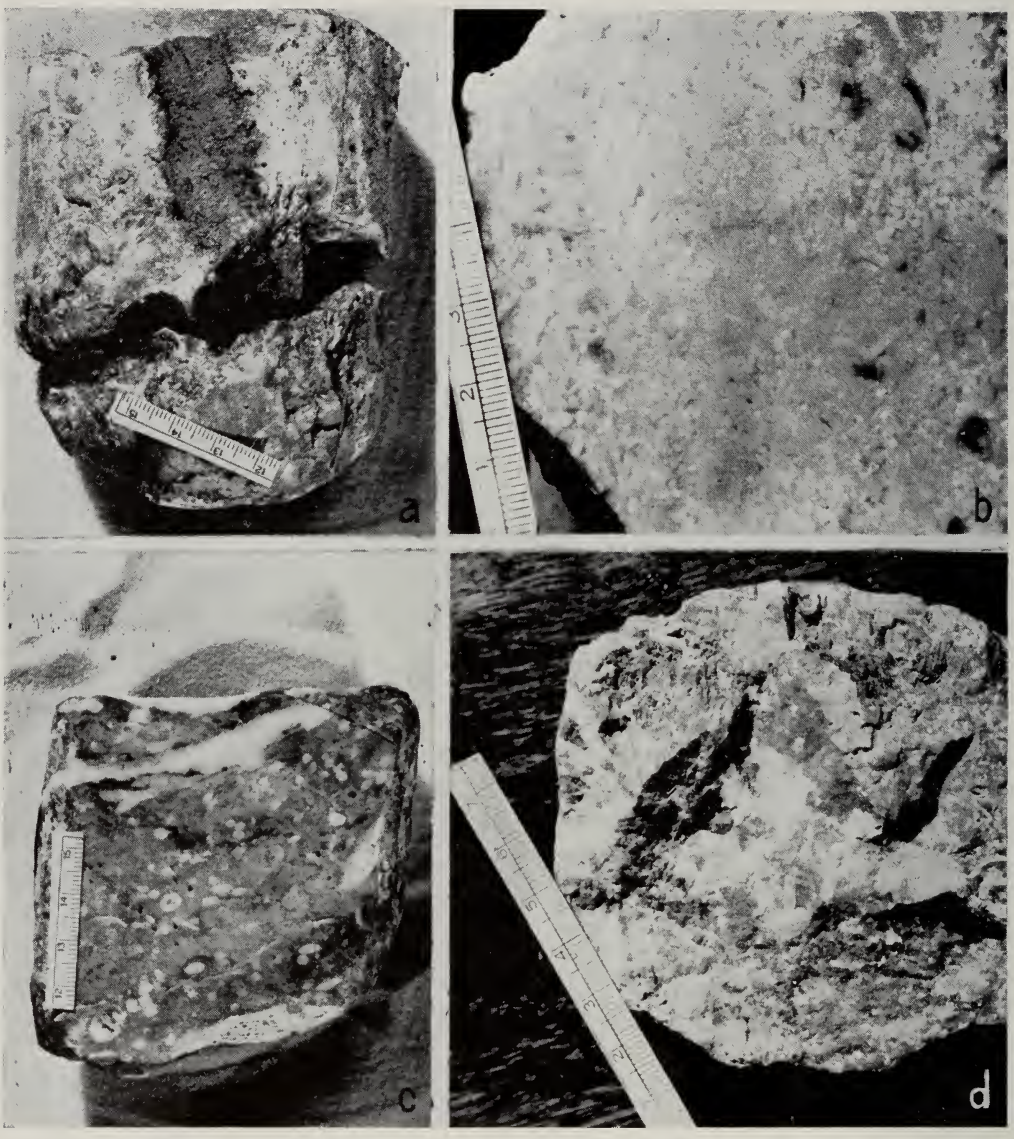

FIG. 12B.—Lithologic character of Niagaran reef deposits: (a) clay-filled fissure in reef-core rock; (b) reef-capping detritus; (c) inclined reef-flank deposits; (d) typical reef-core rock.

distinct Ozark border subfacies that is most prominently developed in the St. Clair limestone of northern Arkansas and southeastern Oklahoma.

The overlying deposits of facies A consist predominantly of red calcareous or dolomitic argillaceous siltstones and subordinately of calcareous silty shales. Pink, green, and purple mottling is common. Green to pink mottled argillaceous crinoidal limestones and occasionally dolomitic limestones form a subordinate lithologic constituent of this upper section.

The chief distinguishing features of this facies complex as a whole are: the very high proportion of silty and argillaceous material, the relatively high iron content that is expressed in the characteristic red coloration, and the absence of chert.

The common fossils noted in cuttings consist of skeletal remains of minute crinoids and of ostracods.

FACIES B

The lithologic succession in the facies B complex is marked by variations and gradations that indicate rapidly shifting conditions of sedimentation. Major units varying in thickness and composition can be traced locally by means of the purer limestone units, but they have not yet been correlated with detailed outcrops.

The predominant rocks are silty, in places argillaceous, light gray to buff fine-grained porous dolomite (Fig. 12 h) with rather low electrical resistivity (Fig. 9). Least common are buff limestones, in part silty and rarely very argillaceous. Intermediate in abundance are transitional silty dolomitic limestones and calcareous silty dolomites. As far as can be ascertained from cuttings, the transitional beds appear to be the product of small-scale interfingering and interlensing of the dolomite and limestone types previously noted. Chert is common in all three types but is sporadically distributed; it is gray to bluish gray and commonly encloses dismembered spicules of siliceous sponges with rare complete sponge skeletons. Fine-grained clastics occur in places and consist of siltstones and less commonly of shales. The siltstones are dark to grayish brown, dolomitic or calcareous, and either grade into, or are interlaminated with, the dolomites and limestones. In well samples the siltstones are apt to be discarded as Devonian cavings because of their resemblance to the Devonian siltstones. Their stratigraphic relationship can usually be determined, however, through cuttings that show either the transition to or actual contacts with the characteristic carbonates of this Niagaran facies complex. Siltstones of identical character are found in this facies complex in outcrops in the Chicago area, for instance in the *Lecthaylus* shale in the Racine inter-reef deposits.[14] Light green to greenish gray shales occur locally as thin laminae and concentrated as lenses and nodules in certain limestones and dolomites, producing a distinct nodular appearance (Fig. 12 e,g).

[14] S. C. Roy and C. G. Croneis, "A Silurian Worm and Associated Fauna," *Field Mus. Nat. Hist. Pub. 298* (1931).

The facies B complex is characterized by light color, fine-grained size, a dominance of silty dolomitic carbonates, and conspicuous amounts of chert. The red colors of facies A are lacking.

The fossils in the facies B complex are chiefly dissociated ossicles of minute fragile crinoids and spicules of siliceous, tetractinellid sponges (Astylospongidae). Solitary and colonial corals are less common. Bryozoans ordinarily are subordinate but become dominant in the argillaceous limestones. The tetractinellid sponges and the small fragile crinoids indicate a quiet-water habitat. The silica of the chert, which is one of the diagnostic criteria of this facies, is derived from sponges.

REEF FACIES

General characteristics.—The reef complex is differentiated from the regional facies by lithologic differences, electric-log patterns, types of bedding, and the fossils.

The reef facies is represented by three major lithologic types: limestones, dolomitic limestones grading into calcareous dolomites, and dolomites. The reef rocks are characterized as a whole by high carbonate content, that is, by their small content of insoluble residues. The reef rocks are commonly 98 per cent or more carbonates, whereas the normal Niagaran rocks with few exceptions, contain less than 90 per cent and commonly less than 80 per cent. Other characteristics are large grain size of the limestones and dark colors of the dolomites. Chert is conspicuously absent in the reef facies, although common in the adjacent normal facies B. The absence of chert is an environmental expression, inasmuch as the sponge populations, whose skeletons supplied the silica for the chert in the normal facies, were ecologically confined to the still-water bottoms surrounding the reefs.

The lithologic character of the reef facies, as compared with that of the normal Niagaran facies, is recognized in the electric logs by consistently higher resistivity and particularly by consistently higher negative self-potentials (cross section, Fig. 9, wells C and D).

Another characteristic feature of the reef deposits is found in the bedding relations, recognizable only in well cores. The reef-mantling detritus is massive with rather few indistinct bedding planes that are horizontal in the upper part and inclined up to 20° in the lower part of the section. All the reef-flank beds are inclined, with dips ranging from 20° to 45° (Fig. 12c). The reef-core rocks are massive and lack recognizable bedding.

The fossil constituents of the reef facies contrast sharply in size, physical appearance, and abundance with those of the normal facies surrounding the reef. The fossils are larger, heavy-shelled to robust, and where they have not been masked or destroyed through recrystallization and secondary dolomitization they are crowded in coquina-like fashion, quite in contrast to the smaller, fragile forms in the normal facies in which the average fossil density is comparatively low. The random orientation of many fossils incorporated in the flank

deposits is a diagnostic feature in cores. The dip slope of the reef flanks is commonly shown by the inclined colonial corals that grew *in situ*. Aside from their physical appearance the reef assemblages can be recognized in cuttings by the relative abundance of colonial corals such as *Favosites* and *Halysites*, of stromatoporoids, and of heavy-shelled pentameroid brachiopods.

Lithologic character of reef components.—As far as has been ascertained, there is gradation rather than sharp delineation of the rock types that compose each of the major reef components, although each appears to be characterized by the dominance of one of the major carbonate types. The gradation is produced by the very irregular distribution and degree of secondary dolomitization, often bordered by a zone in which there was intense recrystallization of the calcium carbonate of the fossils which make up the limestones. The dolomitization commonly obliterates all traces of the skeletal remains and thus the textures of the original rocks, transforming them into uniform fine-grained dolomite. Transitional types consist of dolomites in which a few scattered fossils are selectively preserved in the form of casts and molds or solution-enlarged vugs. The partial alteration of the fossil aggregates into structureless dolomite is apparent even in the well cuttings which show irregular patchy aggregates and discontinuous strands of dolomite crystals cutting across and replacing parts of the fossils. This is shown strikingly in the pink crinoidal coquinas in the basal part of the detrital cap, where scattered dolomitization has corroded the edges of crinoid fragments whose normal bright pink color has been reduced to a small dull maroon patch at the center of the grain. The decoloration appears to have taken place during the recrystallization phase that commonly preceded the dolomitization. Maximum dolomitization occurs in rocks of the reef cores. The reef-flank deposits, as a rule, show less dolomitization and consist predominantly of dolomitic limestones. The reef-capping detritus is normally free of dolomitization in the upper parts but local dolomitization occurs commonly in the basal part that rests on core and flank rock. Lithologic characteristics of the individual reef components are briefly presented.

Reef core.—Reef-core rock, principally known from fore-reefs, consists of structureless dark bluish gray, vuggy dense to finely sucrose dolomite. The visible porosity is principally developed around fossil cavities that were enlarged by solution and along numerous intersecting fractures that characterize the reef cores. The most vesicular parts were not recovered in coring the well that penetrated the fore-reef. The dolomites in the reef core grade peripherally into gray fine-grained dolomitic limestone and calcareous dolomites. The latter enclose lenses of light gray or white coarsely crystalline limestone which represent coquinas unaffected by dolomitization. In cuttings, only the bluish gray dense dolomites can be readily recognized as reef-core rock.

Reef flank.—The reef-flank deposits (known principally from the two edge tests already noted) consist predominantly of dolomitic limestones and subordinately of limestones that always contain some patches of localized dolomitization. To judge from the location of these two wells on the reef, it appears that

the dolomitization may decrease with distance from the main reef core. The dolomitic limestones range from slightly dolomitic limestones to calcareous dolomite and are varied series of interlensing and intergrading relationships. They consist commonly of mottled light gray to gray dense fine-grained vesicular dolomite with scattered residual patches of light gray-white or in places maroon coarse-grained coquina limestone. In the more homogeneous dolomite portions, fossils are commonly preserved in the form of casts and molds.

The purer flank limestones are densely packed aggregates of fossil skeletons which are light gray-white, rarely pink-mottled, medium- to coarse-grained and everywhere show a few localized dolomitic patches. These reef-flank limestones are similar in texture and faunal composition to the reef-capping detritus from which they can not be discriminated in cuttings.

Reef-capping detritus.— The reef-capping detrital deposits represent the best known component of the reef complex because most of the wells bottom in them. They were called the "pink detrital limestone" in the previous report[15] because of their characteristic pink color in the central reef area. These reef-capping deposits consist of pale yellow, less commonly of pink or white, coarsely crystalline limestone that are coquinas of skeletal débris. Dissociated crinoidal remains are the most common constituent. Fragments or entire colonies of stromatoperoids, corals, heavy-shelled pentameroid brachiopods and bryozoans are distributed at random in the smaller-grained crinoidal groundmass. The interstitial spaces between the coquina constituents are commonly occupied by clear secondary calcite or small-grained skeletal débris. Visible porosity consists of fossil cavities, interskeletal spaces of the colonial corals, interstices of the coquina, and discontinuous fissures. Toward the base these detrital limestones become gray mottled and dolomitic wherever they rest on reef rock, and they appear to grade imperceptibly into the underlying dolomitic reef rock. The great variability in thickness of the detrital cap, ranging from 2 to 40 feet, suggests that the boundary of the detrital-transition zone is in part based on irregular dolomitization and in part is a true boundary resulting from irregularities in the reef surface.

Reef border.—Data on the facies relations in the reef border are largely confined to the upper 50 feet of the Niagaran except for the two reef-edge wells already noted and three additional wells, each about 1½ miles from the pool border, that extend through the entire Niagaran section.

Information provided by these wells, although contributing few data on contact relations between reef and reef-border facies, has established the fact that the gradually expanding reef complex influenced and at times controlled the sedimentation conditions of the reef-bordering tract within a radius of approximately 2 miles.

The influence of the reef on the sedimentation conditions within this zone is shown principally in two ways: (1) by the direct contribution of reef-derived detritus, and (2) indirectly by causing turbulence in the surrounding water so

[15] H. A. Lowenstam and E. P. DuBois, *op. cit.*

that the fine terrigenous clastics were not deposited but by-passed the reef-bordering tract. These sediments, carried in suspension in the Niagaran sea, would have normally been deposited in this zone but settled outside instead. Because these opposite effects on sedimentation largely compensated each other, there are no noticeable deviations from the normal thickness.

The most conspicuous evidence of reef control of sedimentation is shown by the character and thickness relations of the lower regional facies A, whose basal section is known to extend without replacement under the marginal reef-flank deposits. Starting about 2 miles away from the reef complex, typical facies A sediments thin reefward from the regional average of about 150 feet to 50 feet or less under the reef-flank edge. This thinning took place entirely in the upper silt-bearing part of facies A, through the progressive decrease in deposition first of the terrigenous *terra rosa* constituents followed by elimination of the relatively coarser terrigenous components. As the silt and clay decreases reef-derived fossil débris is added in increasing amounts close to the reef border. The composite effect of these two factors on sedimentation is responsible for the development of a ring of atypical sediments that rests on the reefward thinning edge of the typical regional facies, producing the impression that the facies thins approximately 100 feet (Fig. 10). In the two wells on the eastern fore-reef ridge the reef deposits are underlain by 90 and 100 feet of Niagaran sediments that include at the base 55 and 40 feet, respectively, of the typical pink to red, slightly argillaceous basal limestones of facies A. The overlying 35 and 60 feet of sediments that intervene between these typical facies A rocks and the reef deposits are mottled greenish gray slightly argillaceous limestones and dolomitic limestone interlaminated with mottled drab greenish coarse siltstone. In at least one of the wells, white and pink crinoidal remains coarser in size than the normal facies A constituents increase in abundance upward toward the reef base. Terrigenous clastics in the uppermost part closest to the reef are confined to light green clay patches that occupy the interstices of the crinoidal semi-coquinas. This atypical non-red phase of facies A can be differentiated from the normal sediments of the overlying facies B by the relatively smaller amount of silt, by lack of chert, and particularly by the green shale that everywhere occurs in conspicuous amounts in this section. The occurrence of these reef-modified sediments under the fore-reef ridge implies that the reef development started at a more centrally located part of the reef complex at least by the time the highest beds of the basal limestone part of facies A were laid down. The reef thus began during a relatively clear-water phase, and as the atypical facies deposits further imply, must have stood high enough above the sea floor during the succeeding muddy phase to affect conditions of its bordering tract in the manner described. Evidence of mass deposition of the detrital fraction that could not settle in the reef and border areas may be seen in the abnormally thick section of facies A about 3 miles north of the pool in the SW. $\frac{1}{4}$, NE. $\frac{1}{4}$, NE. $\frac{1}{4}$, Sec. 21, T. 5 N., R. 6 W., where the facies complex attains a thickness of 186 feet, which is 35 feet more than the average regional thickness.

In the section occupied by regional facies B, the reef influence is primarily expressed by the interfingering of the normal facies with reef-derived detritus. This detritus occurs in tongues, forming direct marginal extensions of the reef-capping detrital blanket and radially thinning wedges that probably project at varying levels from the detrital reef-flank beds. The readily recognizable detrital tongues are coquinas of sorted reef-derived débris, that grade vertically and laterally into coquinas which contain terrigenous silt. The marginal expressions are thin stringers of small-grained skeletal aggregates that occur in the normal silty fine-grained dolomites. The relatively large amounts of fine-grained pure limestone, with or without chert, that are intercalated between normal regional facies sediments in the outer zone of reef-controlled deposition are interpreted (Fig. 10) as the edges of detrital fans that consist of sorted reef detritus of fine sand size. It is evident that a reef complex of the size and areal extent of the Marine reef must have contributed to the bordering tract considerable quantities of clay-sized detritus in the form of reef milk which can not now be recognized unless by gross shifts of the carbonate-clastic ratios. Local concentrations of clay and silt appear to be more common in the outer edges of the border area than in the normal unaffected areas. This observation may be unrepresentative due to the more intense study of Silurian sediments near the pool; or it may be actual and represent by-passed excess terrigenous clastics deposited in still-water environments protected by the reef or by detrital tongues. The possible control of clay flocculation near reefs due to variations in ion concentration and possibly pH resulting from the effect of mass fixation of calcium carbonate by the reef-building organisms should be considered.

A mechanical explanation may also enter into the interpretation of the thin part of facies A, directly underlying the reef complex. It has been ascertained that certain recent reefs have settled into the plastic substratum, as the result of the increasing load of the expanding rigid reef bodies, causing the loaded sediments to squeeze out marginally.[16] Similarly, sagging of the inter-reef strata at the periphery of certain Niagaran reefs in northern Indiana has been interpreted by Cumings and Shrock[17] to have been caused by reef settling. It is therefore conceivable that the maximum thinning of facies A under the reef complex in the two wells that cut the reef margins (Fig. 10, wells C and I) may have to be partly accounted for in similar manner. There is no evidence to prove that the thinning initially caused through the by-passing effect of the reef on the fine terrigenous clastics (with insufficient compensation through reef-derived detritus) was accentuated through squeezing out of additional sediments. It is true, however, that wells have not yet been drilled through the critical areas just off the reef margins, where the stabilizing zone should be located, in which the squeezed-out material should cause bulging of the thin facies A sediments.

[16] Sluiter, quoted by: E. R. Cumings and R. R. Shrock, "The Geology of the Silurian Rocks of Northern Indiana," *Indiana Dept. Conservation Pub. 75* (1928), p. 145.

[17] *Ibid.*

ALEXANDRIAN

The Alexandrian is represented by the Sexton Creek (upper) and Edgewood (lower) formations that show no anomalies in lithologic character or thickness in the two reef-edge wells as compared with wells outside the pool area.

The Sexton Creek formation consists of 15–40 feet of white to buff finely crystalline limestones and here and there dolomitic limestones. Glauconite pellets are commonly present in the top sections, and light-colored opaque chert containing sponge spicules occurs in greater concentration in the basal section. The glauconite and chert, coupled with the lack of pink to red crinoidal grains, readily differentiate the Sexton Creek strata from the overlying basal limestones of the Niagaran regional facies A, although they can not be readily separated on electric logs. The formation ranges in thickness from 15 to 40 feet.

The Edgewood formation in the area consists of light brown to buff finely sucrose commonly porous dolomite that contains silt and fine sand in variable amounts and ranges from 15 to 22 feet in thickness.

PALEOGEOGRAPHIC ASPECTS OF MARINE REEF IN RELATION TO NIAGARAN REEF DISTRIBUTION

The Marine reef is as large as any Niagaran reef yet known, and because most of the other reefs occur in groups, it seems reasonable to assume that the Marine reef may be part of a reef belt. Niagaran reef rock has been cored near Arthur, Moultrie County, Illinois, and near Covington, Fountain County, Indiana. These previously unknown reef occurrences suggest a reef belt lying south of the Michigan basin belt or linking that belt to the Ozark border (Fig. 13).

STRUCTURE

The Marine pool structure, as shown on top of the Silurian (Fig. 14), does not resemble a normal deformational structure in Illinois. As pointed out, the horseshoe-shaped Marine structure is primarily an expression of the reef topography, slightly modified by pre-Wapsipinicon erosion, and possibly by subsequent minor structural wrinkling. There is a total of 120 feet of closure with the highest part rising 40 feet above the main-reef plateau.

The Marine pool structure as shown on top of the Silurian is reflected almost identically in the Devonian but becomes gradually less accentuated in the Mississippian and still less in the Pennsylvanian beds.

Specifically, the structure on top of the Devonian limestone is only slightly modified and the closure is reduced to about 110 feet. On the Lower Mississippian surface which lies 900–950 feet above the Silurian, the structure, as shown in Figure 15, is considerably more generalized and the closure is reduced to 70 feet. The reef topography is accurately outlined so that the Lower Mississippian surface can be used for structure tests. The structure on top of the Lower Pennsylvanian Seahorne limestone is still further generalized but shows a closure of 60 feet as seen in Figure 16. The map is less detailed than the other

two because fewer datum points were available. There is also 60 feet of closure on top of the prominent Piasa limestone that lies only 250 feet below the surface. The structure, however, is greatly modified here, apparently due to channeling and unequal deposition near the No. 6 coal horizon, which prevents this otherwise desirable Upper Pennsylvanian marker from being used for shallow structure testing.

The data presented in the stratigraphic analyses of the Niagaran facies and thickness relations in the pool area clearly imply that the Marine pool structure is not a product of deformational forces but is solely an expression of compaction

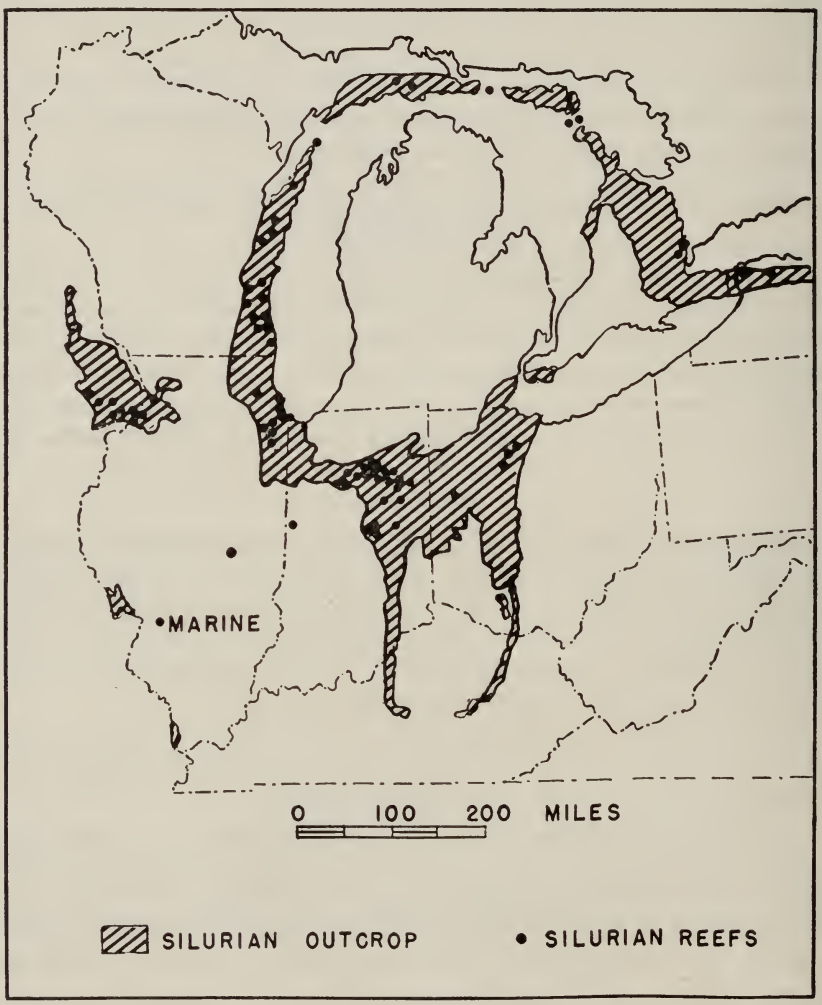

FIG. 13.—Map showing Silurian reef distribution in east-central North America. After Cumings and Shrock (*Indiana Dept. Conserv. Publ. 75*, Fig. 44), modified by the writer, incorporating data from Shrock, G. M. Ehlers, H. B. Willman, and Carl A. Bays.

of the normal Niagaran sediments surrounding a rigid reef complex under the load of accumulating sediments. If this interpretation is correct it would follow that the Marine pool structure does not extend into the pre-Niagaran strata. To examine this interpretation critically two regional structure maps, one on the Silurian and another on the Galena (Kimmswick) or "Trenton," were prepared to include the St. Jacob and Grant Fork structures that are known to be of deformational origin.

The structure on top of the Silurian (Fig. 8) shows the Marine and St. Jacob pools as a generally north-south alignment of two distinct structures with the Grant Fork structure at the northeast on the eastward-tilted shelf segment of the Eastern Interior basin. The "Trenton" map (Fig. 7) shows nearly identical structure excepting the Marine pool area. The Marine structure, as expressed on

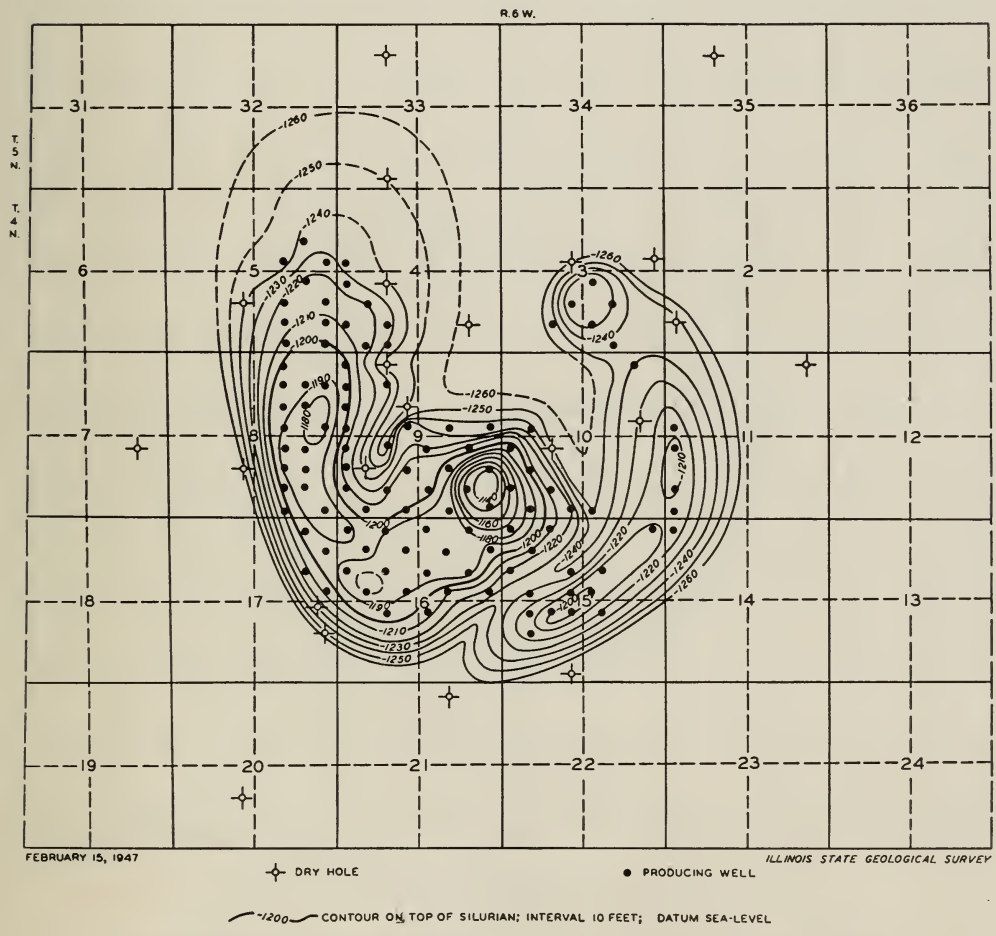

FIG. 14.—Structure on top of Silurian, Marine pool.

the Silurian surface, has not been carried downward. Instead, there is only a slight flattening of the regional dip indicating no more than the ordinary undulations found with this much control. In analyzing the data on which the flat "Trenton" structure is based, it is seen that the "Trenton" tops of the two wells in the eastern third of the Marine pool are practically on strike and in harmony with the regional dip, in contrast to the structural high, which is expressed by the Silurian tops of the same two wells where it is explained by the excess thickness of the reef deposits. No "Trenton" data are available for the western two-thirds of the Marine structure. It is, therefore, possible that a small "Trenton" structure may underlie this part of the pool.

However, the interpretation that the western two-thirds of the Marine structure is of the same origin as that proved for the eastern third seems reason-

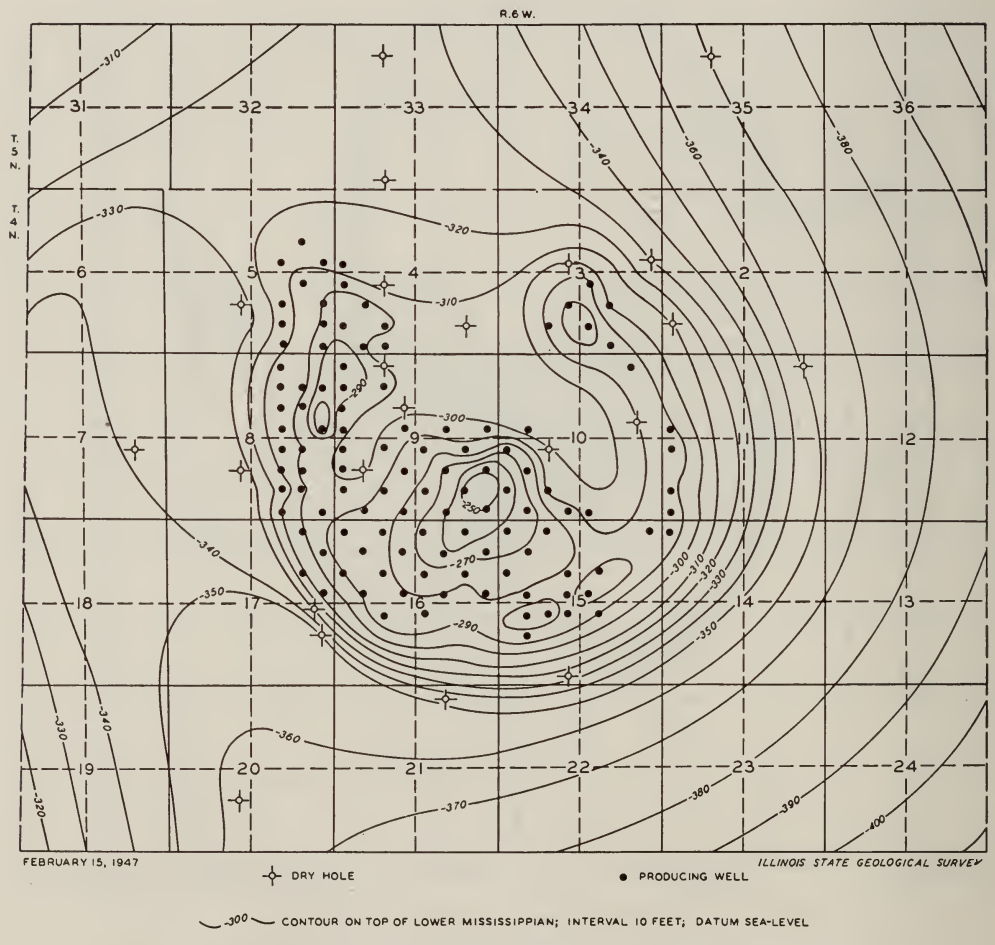

FIG. 15.—Structure on top of Lower Mississippian surface, Marine pool.

able because: (1) the distribution of the reef facies in the upper 50 feet of the Niagaran coincides with the entire structural high, (2) the zone of controlled sedimentation forms a halo of approximately equal width around the entire structure, (3) the presence of the atypical phase of facies A underneath reef sediments in the two edge wells demands an earlier reef start in a more centrally located area. This implies a thicker reef section in the direction where actually we find the highest part of the Marine structure.

From consideration of these stratigraphic data it seems unlikely that there is even a small "Trenton" structure under the western two-thirds of the pool. If this is correct, it would appear that the seismograph data that have been interpreted as indicating a "Trenton" structure in the Marine pool area actually reflect a seismic-wave velocity in the pure carbonate reef-body that differs from

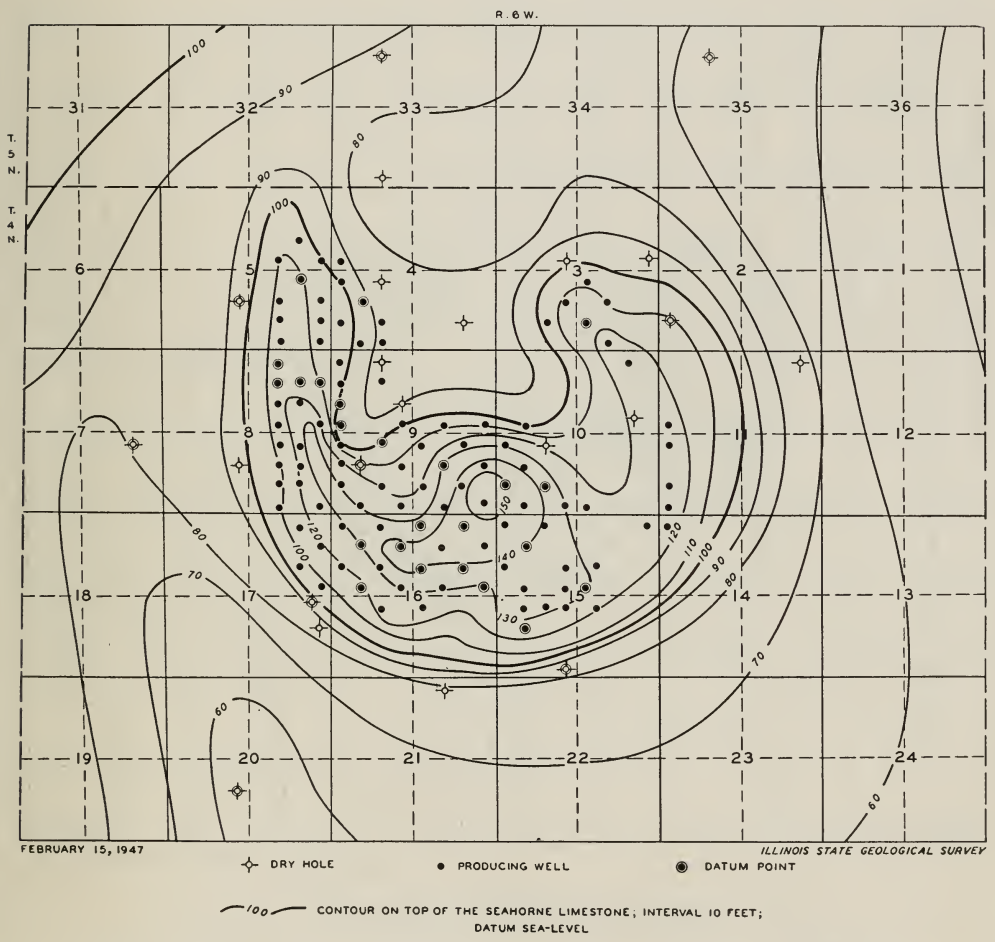

FIG. 16.—Structure on top of Lower Pennsylvanian Seahorne limestone, Marine pool.

the wave velocity in the normal silty argillaceous sediment and thus creates a false "Trenton" high.

The isopach maps (Figs. 3, 17, 18) show that thinning over the structure amounts to about 10 feet in the Devonian limestone, about 40 feet between the Devonian and the Lower Mississippian surface, and about 20 feet between the Lower Mississippian surface and the Lower Pennsylvanian Seahorne limestone. The total thinning over the reef is thus about 70–80 feet. As the Silurian structure shows a total relief of 120 feet, it implies that nearly 40 per cent of the compaction of the Niagaran extra-reef beds must have taken place in post-Pennsylvanian time.

There are numerous problems connected with the compaction phenomenon, particularly regarding the compaction over the reef channels that can not be

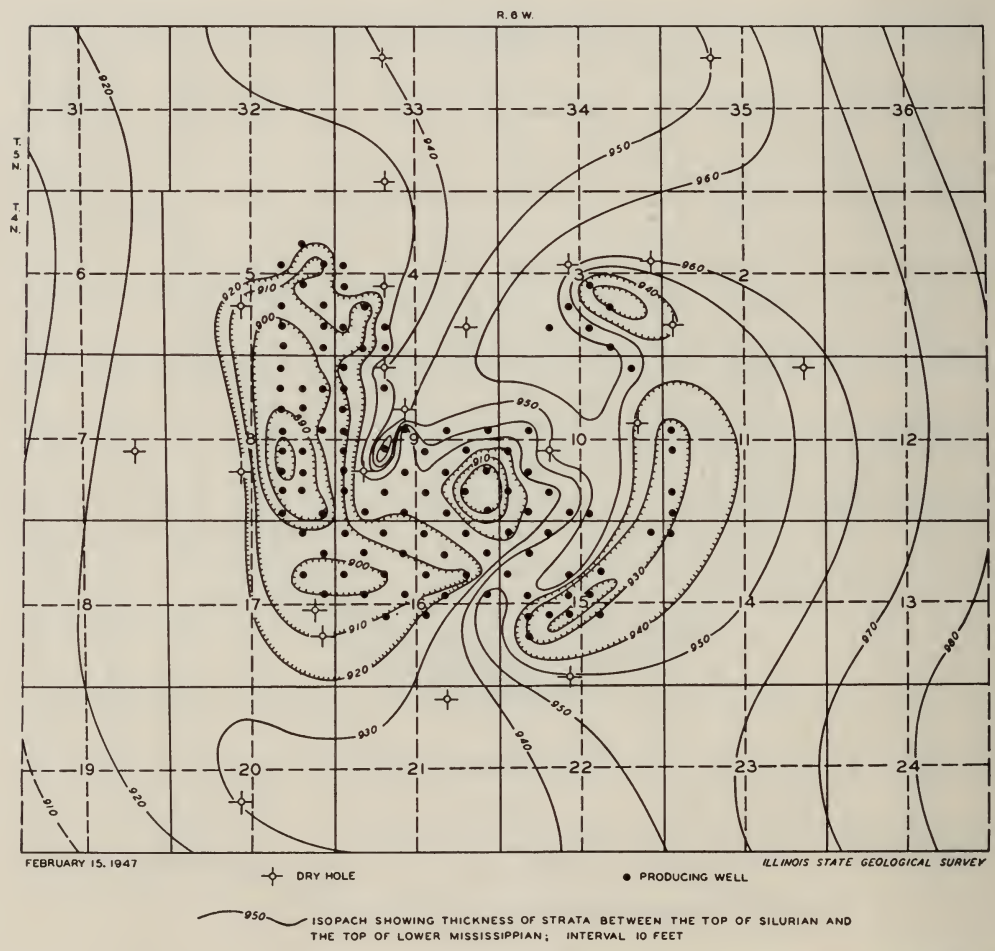
R. 6 W.
T. 5 N.
T. 4 N.
FEBRUARY 15, 1947
ILLINOIS STATE GEOLOGICAL SURVEY
DRY HOLE
PRODUCING WELL
950 ISOPACH SHOWING THICKNESS OF STRATA BETWEEN THE TOP OF SILURIAN AND THE TOP OF LOWER MISSISSIPPIAN; INTERVAL 10 FEET

FIG. 17.—Isopach map of interval between top of Lower Mississippian and top of Silurian in Marine pool.

satisfactorily explained and will require a more detailed analysis. Analyses of the isopach relationships for units that are not bounded by erosion surfaces may be helpful.

PRODUCING ZONES

Most of the oil produced in the pool is from the Niagaran detrital limestones which blanket the reef, principally from the Silurian-Devonian contact and from three lower discontinuous porous streaks. Little is known about the thickness of the producing streaks because the wells, as a rule, were bottomed in the top 1–4 feet to prevent early water encroachment. The maximum thickness reported is 5 feet, but this thickness appears to be exceptional. Less than half a dozen wells

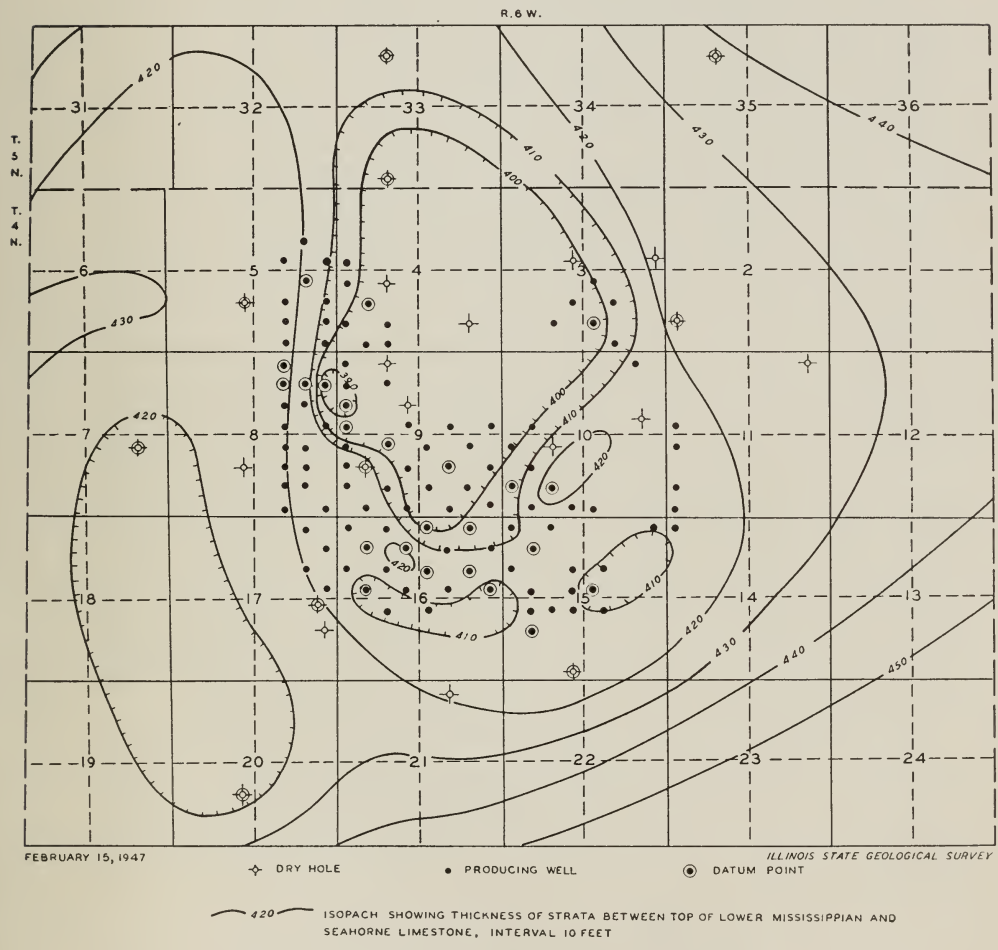
R.6 W.
T. 5 N.
T. 4 N.
FEBRUARY 15, 1947
ILLINOIS STATE GEOLOGICAL SURVEY
DRY HOLE
PRODUCING WELL
DATUM POINT
420 ISOPACH SHOWING THICKNESS OF STRATA BETWEEN TOP OF LOWER MISSISSIPPIAN AND SEAHORNE LIMESTONE, INTERVAL 10 FEET

FIG. 18.—Isopach map of interval between top of Lower Pennsylvanian Seahorne limestone and top of Lower Mississippian in Marine pool.

are known to produce from reef-flank or reef-core dolomites. They include the discovery well that produces from a fore-reef and a recently deepened well in the NW. $\frac{1}{4}$, SE. $\frac{1}{4}$, NW. $\frac{1}{4}$, Sec. 17, that produces from the top 7 feet of the main reef. In general the producing beds occur in the top 35 feet of the Silurian strata. The average daily production and the cumulative production as shown in Figure 19 demonstrate that none of the discontinuous porous streaks appears thick enough to have the storage capacity correlative with the amount of fluid produced. It is the writer's opinion that the network of secondary porosity zones lining the fissure system and a crevice system connect the discontinuous producing streaks with each other and with the main reef core underneath, forming one common reservoir.

Minor amounts of oil are produced from two higher zones, the Wapsipinicon and the lenticular sand bodies of Hardin type, developed either in the Cedar Valley limestone or on top of it. The Wapsipinicon producers, as determined by sample studies, are with one exception structurally low wells and are all located on the east side of the pool. They occur on the border of the slopes of the two inlets that separate the main Niagaran reef structure from the eastern fore-reef ridge and in the depressions separating the individual fore-reefs. The Wapsipinicon production is best explained as fissure production from the Niagaran reef reservoir. The limestones and dolomites are uniformly tight. Because the samples from deepening of the producing levels ordinarily show intense fissuring, it is assumed that the oil is produced from the Niagaran reef reservoir by means of the fissure system that extends from the Wapsipinicon surface downward into the Niagaran reef. The restricted occurrence of the known Wapsipinicon producers along the east side of the field requires further consideration. It will be noted that all but one of them are located in or on the slopes of the drainage course that had been developed in pre-Wapsipinicon time on the Silurian surface (Fig. 16) and on structurally low segments. It thus appears that initially solution was selectively accentuated along the pre-Wapsipinicon drainage course in the top of the detrital reef-capping limestone. Subsequent compaction of the deposits over the Niagaran reef depressions probably affected primarily the clay-filled and sand-filled fissures in the rigid Wapsipinicon rock, resulting in reopening of the fissures along the wall contacts with the fill. This would account for production at these points above the Niagaran producing streaks.

The higher Devonian producing sand is located only over the southwestern reef edge, although similar sand lenses occur structurally higher on the west side of the pool. The localized oil produced from this sand lens can be readily explained by its occurrence overlying and in contact with Niagaran reef rock. The porous sand, free from cementing matrix, formed an ideal reservoir for oil from the reef rock.

COMPLETION PRACTICES AND PRODUCTION

1. Wells are commonly drilled by rotary tools to the first hard break in the Devonian, ordinarily at the top of the Cedar Valley formation but in places in

DAILY AVERAGE PRODUCTION IN HUNDREDS OF BARRELS
CUMULATIVE PRODUCTION IN HUNDREDS OF THOUSANDS OF BARRELS
CUMULATIVE PRODUCTION
DAILY AVERAGE PRODUCTION
PRODUCERS COMPLETED EACH MONTH
TOTAL PRODUCING WELLS
TOTAL PRODUCING WELLS
PRODUCERS COMPLETED
EACH MONTH
J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N
1943
1944
1945
1946

FIG. 19.—Drilling and production curves, Marine pool.

the unnamed overlying siltstone unit or, in a few places, in the Wapsipinicon limestone. Casing, usually of 7-inch diameter, is cemented and the well is "tailed in" cautiously with cable tools. In general, drilling is stopped at the first soft streak, rarely in the Devonian but usually in the Silurian, and the producing beds are acidized with only 50–100 gallons of acid. Phenomenal increases in fluid production are commonly caused by these very small amounts of acid. If neither commercial amounts of oil nor large amounts of water are obtained, the well is further deepened by 1-foot or 2-foot runs, and any other soft streaks may be acidized. Some wells are completed without acid treatment. During the earlier development of the pool some wells were shot with 10–30 quarts of nitroglycerine and in others acid charges of several thousand gallons were used.

2. On January 1, 1947, there were 108 producing wells in the field (Fig. 19), spaced one well to 20 acres but with different spacing patterns in different parts of the field. The field is still being developed. Average daily production for the field on January 1, 1947, was 3,200 barrels, and the cumulative production was 2,528,000 barrels. Ultimate recovery of 6,000,000 barrels is estimated by the Illinois State Geological Survey. The oil gravity varies between 34.0° and 35.5° A.P.I.

3. The Marine pool has produced large amounts of water. Lack of data on water production on many leases prevents a quantitative evaluation, but the following generalizations appear valid. Although there are many exceptions, wells completed high on the structure, high stratigraphically, with low productive capacity and with little acid treatment, have tended to have lower water-oil ratios than similar wells lower, larger, or more heavily acidized. However, a picture of a simple oil-water contact can not be upheld, as the water-oil ratio of the lowest producing well in the pool is less than that of certain wells more than 60 feet higher. Up to January 1, 1947, the estimated total water production was approximately 8,000,000 barrels, as compared with an oil production of 2,538,000 barrels. However, the water-oil ratio for the field as a whole has risen, and in the spring of 1947 approximately 6 or 7 barrels of water were lifted for each barrel of oil. Brine is disposed of by injecting it into the Salem limestone of Mississippian age.

4. There is no gas cap and probably less than 10 cubic feet of dissolved gas per barrel of oil. Pressure has declined from an original pressure of a little more than 700 pounds per square inch to as little as 100 pounds in some of the older leases at the center of the pool (March, 1947), as estimated from fluid levels in reworked wells. Operators have not yet attempted repressuring or pressure maintenance, but generally believe that some form of injection should be used to offset the rapid decline in pressure.